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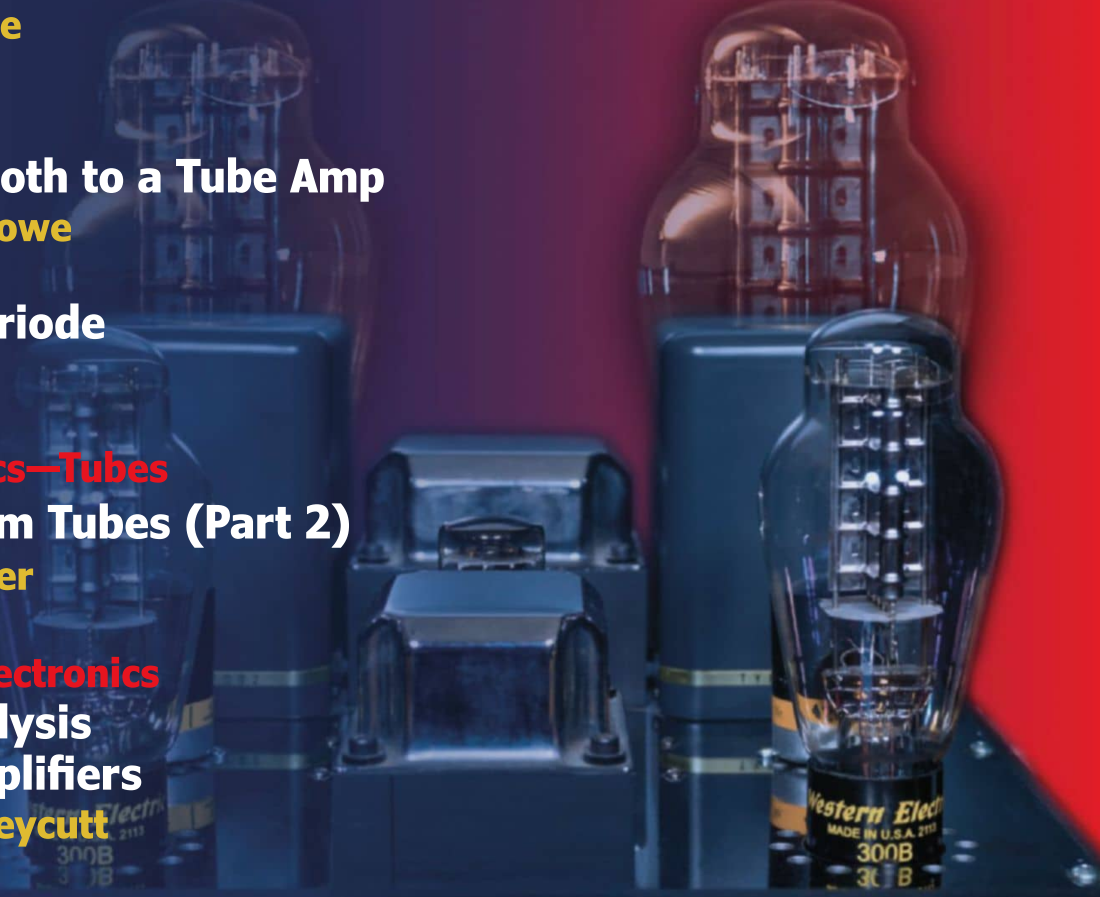

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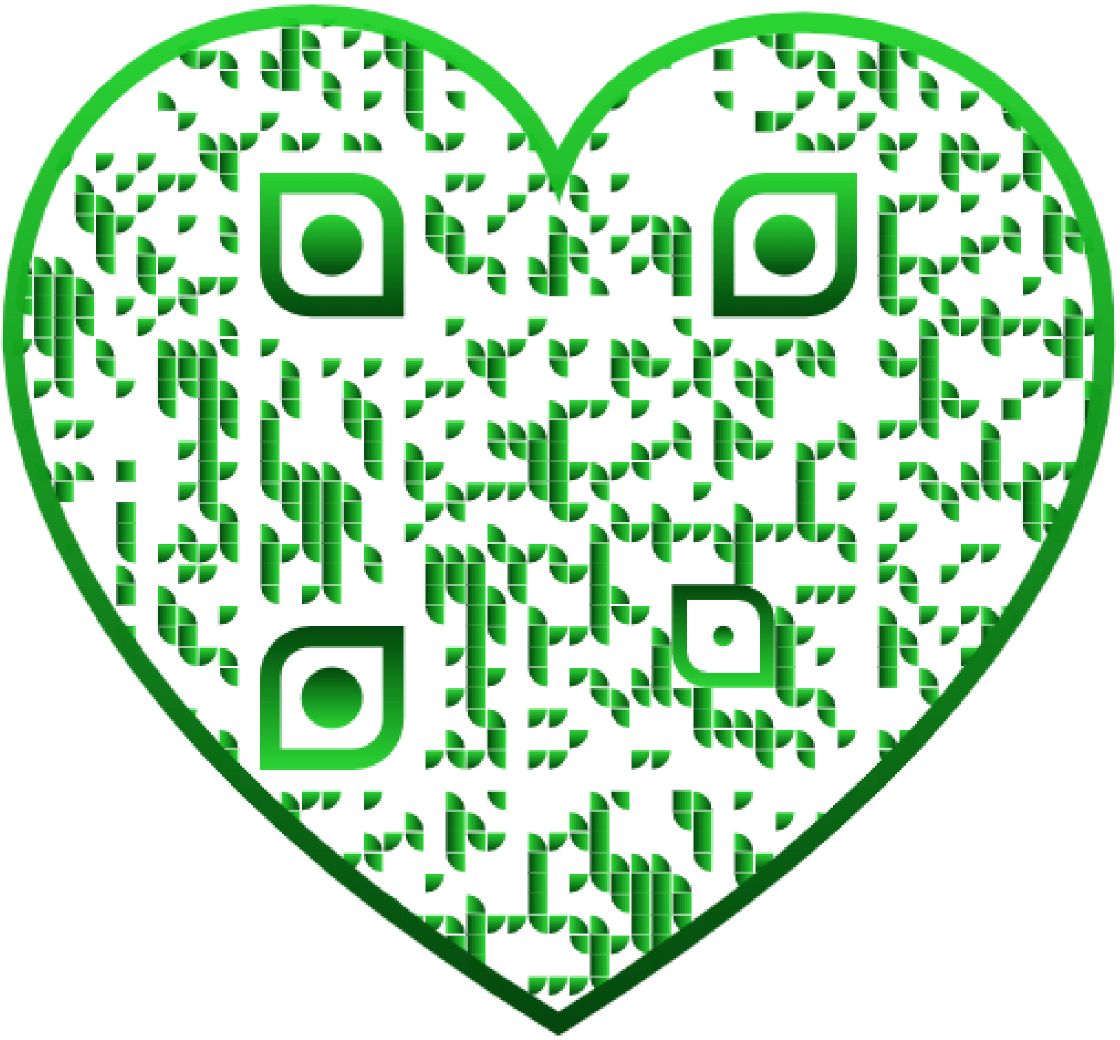

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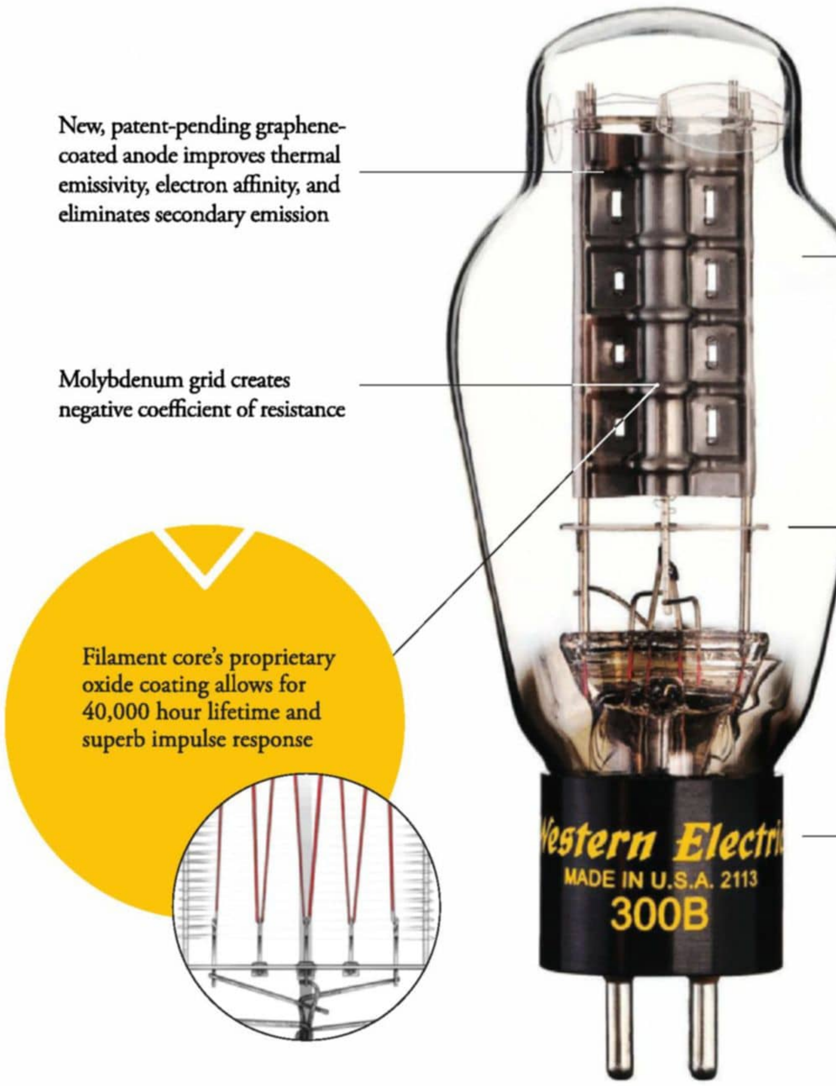

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The End of Cheap Tubes

Every year, when I focus on this Glass Audio issue of *audioXpress*, I like to dive into the archives and revisit a selection of the issues that Ed T. Dell produced twice a year, beginning in 1988. In 1990, in his column "Valve Views," contributing author Ken Kessler wrote "As you sit there poring over the latest *Glass Audio*, perhaps a small part of you is wondering: Am I devoted to a branch of hi-fi so obscure it could disappear at any moment? Believe me, such doubts affect us all at times, and not only when you hear of another tube amp manufacturer (or tube manufacturer, for that matter) closing up shop."

The harbinger was there, but this was shortly after the collapse of the Berlin Wall, in December 1989, leading to the end of Soviet Union, and Russian tubes flooding the market. Anticipating the revival of tube audio in hi-fi, Kessler, also predicted in that article: "Tubes are going to be around for a long time."

While browsing *Glass Audio* issues, two years later I noticed a text-only ad from New Sensor, announcing the availability of Soviet "selected military" tubes, which mentioned the fact that Eric Clapton had "replaced the Philip/Sylvania 8L6 STRs in his custom Soldano amp, which he uses live with Soviet 5881s because of their "milky smooth sound."" The same ad also promoted GE, Siemens, EI, Sylvania/Philips, and other tubes, sold at the time by the New York, NY company, owned by Mike Matthews (Electro-Harmonix).

In later editions, an Old Colony Sound Lab house ad promoted Charles Hansen's book, *A Brief History of Bendix Red Bank Tubes*, (https://cc-webshop.com/products/a-brief-history-of-bendix-red-bank-tubes) revealing the mystery around those "highly reliable tubes made for the military for use in guided missiles." Charles (Chuck) Hansen (the *audioXpress* author) was himself employed at Bendix Aviation Corp., based in Eatontown, NJ, from 1966 to 1998. When Hansen joined Bendix, the company had by then stopped making tubes and used all-discrete transistor designs exclusively. His father worked there as well, as a tool and die maker, and developed much of the tooling used in the Red Band Tubes manufacturing until the 1950s. As Hansen recalls in his book, his grandfather and uncle worked at the S&S Manufacturing Corp. tube assembly business in Newark, NJ in the 1920s and 1930s. That company made plates, grids, tube supports, and other parts for Chatham, Tung-Sol, and Arcturus.

In the 1990s, a large surplus of these military tubes were still being auctioned, and the market was flooded with cheap tubes coming from Russia and other Eastern European countries that were part of the former USSR. It just didn't make sense to keep manufacturing tubes in the US or even in Western Europe.

When, in the early 2000s, the last remaining tube manufacturing operations, mainly producing tubes for televisions and computer monitors gradually closed, musical instruments, recording studio equipment, and hi-fidelity were the only markets left for tube makers.

Fast forward to 2022, and the war in Ukraine and the sanctions imposed on Russia are having a significant impact on the global supply of tubes to the audio industry. As I wrote in *The Audio Voice* newsletter, both Ukraine and Russia are important suppliers of raw materials, and in China there are also significant disruptions caused by pandemic lockdowns and transportation challenges, resulting in huge cost increases.

There are not many tube manufacturers left in the world, and the ones that exist, still depend on this challenging global supply of parts and materials. This means that the tubes required in the audio industry will remain scarce, and that prices are certain to increase exponentially.

On a positive note, while targeting the higher end of the audio market, Western Electric has successfully resumed manufacturing 300B tubes in its state-of-the-art Rossville Works in Rossville, GA, as reported by *audioXpress* and accounted with a review in this issue. To bring tube manufacturing back to the US, Western Electric also acquired the know-how and machinery from many of the former leading European tube factories and is now equipped to handle production of multiple tube types. On March 2022, Western Electric sent out a (soft) announcement confirming "plans to expand tube operations" to produce other tube types. We hope to report more information about this in our next *Glass Audio* special, in May 2023.

J. Martins

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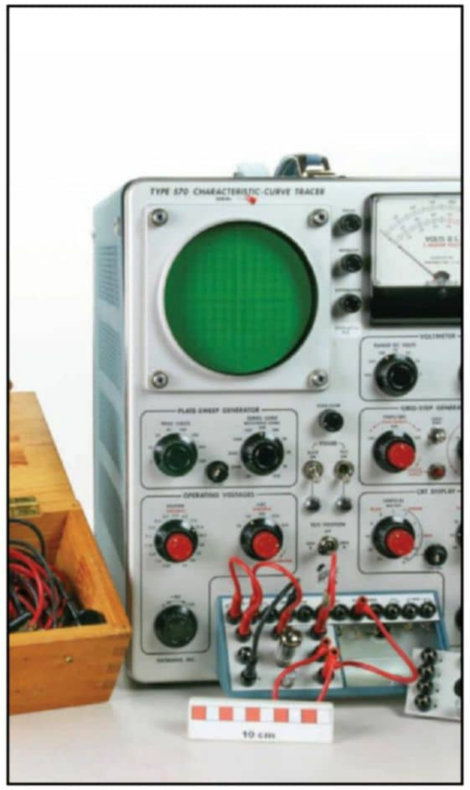

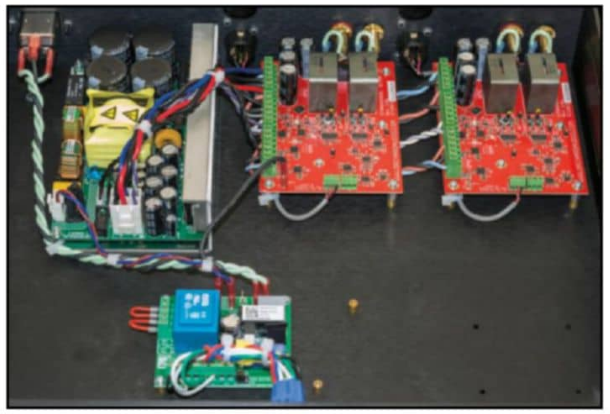

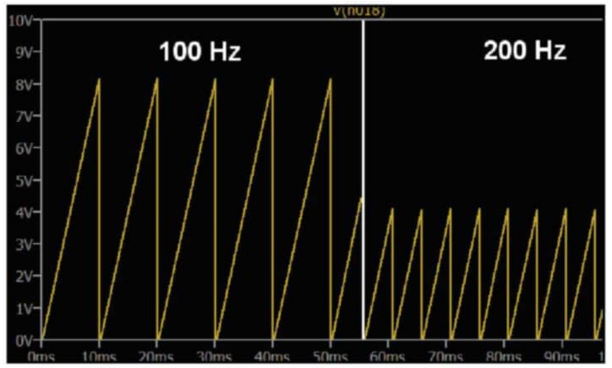

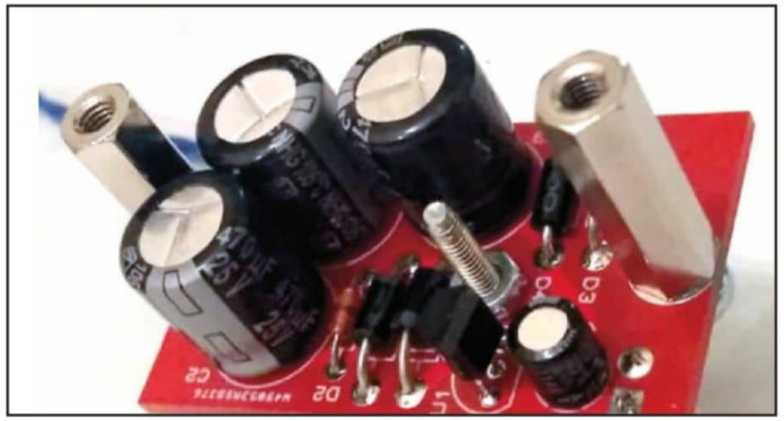

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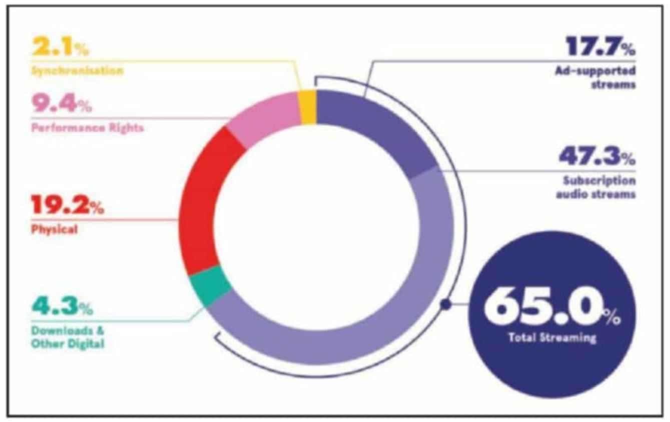
The Enduring Appeal of Vinyl

By
J. Martins
(Editor-in-Chief)

Sales of vinyl records are again a respectable revenue source for the music industry, representing more than $3.4 billion of the $26 billion USD in global revenues achieved in 2021. No wonder, the audio industry is responding accordingly with new products for all price segments.

Three different groups, across generations, currently have completely different perspectives about the world of vinyl records. There are obviously the experts, composed at the extremes by historians, collectors, and preservationists, side by side with extreme high-end aficionados willing to devote personal fortunes for the ultimate gravitation-denying turntable mechanics and ultrasonic cleaning machines. The majority in that group are simply those users who remain attached to vinyl, have kept their record collections, and keep a decently working turntable at home.

Then, there's the intermediate group of people who have lived most of their lives with the convenience of the Compact Disc (CD) and digital, now disillusioned by the demise of digital downloads. In most cases, for that group, records and turntables are synonymous with rumble, scratches, clicks, pops, record skips, and bad pressings, and most importantly, unbearable inconvenience. Strangely enough, a small percentage within that group were DJs, and kept an intense relationship with a different kind of turntable, while amassing large quantities of records.



Global Recorded Music Revenues by Segment 2021, according to the IFPI "State of the Industry - Global Music Report 2022"

Then there's the younger generations of vinyl explorers who have rediscovered the pleasures of "touching" music and appreciating the cover art and liner notes while playing records. That is the demographic responsible for the vinyl revival, and the ones who generated news headlines when vinyl sales resumed growth. In reality, this is a diverse group of consumers, most of which maintain a relationship with music that transcends media formats.

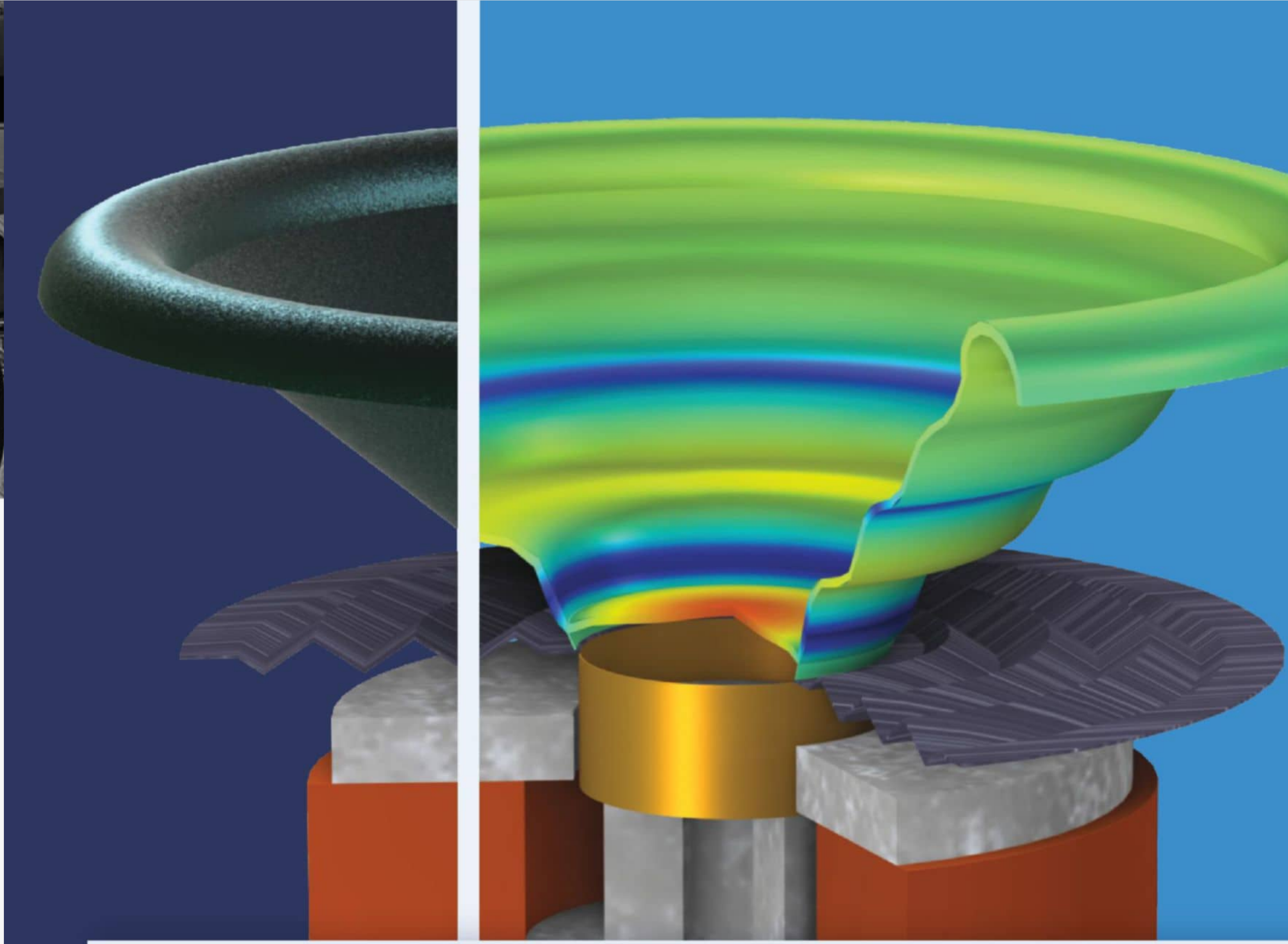
The younger generations are actually buying vinyl in the same way they would buy App Store gift cards. It's a collectible physical object that can be appreciated, includes a code for digital download, and now increasingly also a subscription voucher for music streaming services. A clever way for music subscription services to get new users to sign up for their premium services.

While consumer characterizations are always debatable generalizations, the audio industry is well aware that the general knowledge about the equipment required to enjoy vinyl is very superficial. Understanding what makes playing vinyl records a pleasant and unique experience varies even more. And that explains why cheap, plastic portable turntables and record players in traveling suitcases with built-in speakers are making a comeback.

What's Phono?

Phonograph, gramophone, record player, and turntable, are now all generic names associated with rotating discs, called "records." Some of these names used to be trademarked, and for current generations they are all distant—and sometimes confusing—references. Let's not even discuss what current vinyl enthusiasts know or understand about a stylus, cartridges, or tonearms.

A more interesting discussion is related with the term phono. Outside of the hi-fi world, very few people know that the RCA Phono connector, now commonly used to carry audio and video signals, derives from the original Radio Corporation of America design intended to connect a phonograph to a radio receiver. Overtime, phonograph was abbreviated to "phono" and the connector, which is still used in phono inputs, became known as just the RCA connector,



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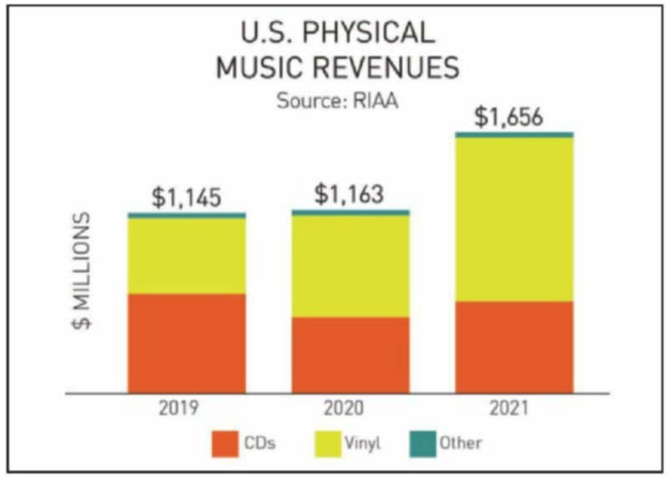


According to the RIAA, for the first time since 1996 US physical music revenues have seen growth in both CDs and vinyl records in the same year. The resurgence in vinyl records continued for the 15th consecutive year, as revenues grew 61% to $1 billion USD in 2021. The last time vinyl records exceeded $1 billion was 1986. Vinyl accounted for 63% of revenues from physical formats, and 7% of total music revenues.

In 2021, The House of Marley launched an unpretentious bookshelf speaker design, expanding its popular “Get Together” line of Bluetooth 5 speakers that is a great match with the brand’s “Stir it Up” wireless turntable in matching bamboo finish.

Consumers will be easily lead to think that vinyl is an affordable option when they see this Crosley T160A-GY T160 two-speed turntable and matching speakers retailing for just $189.95.

while “phono” is understood by consumers as the pre-amplification input required for a turntable. But for younger generations who never heard about Recording Industry Association of America (RIAA) equalizations, don’t understand the specifications of millivolt “phono” signals, and don’t really want to deal with the technical aspects of connecting audio equipment, more and more turntables are now available with standard line level outputs (same RCA cables and connectors!) or even USB interfaces.

Let’s not forget that, at least until approximately 2010, one of the largest “pro audio” equipment markets was the DJ (disc jockey or Deejay) segment, which traditionally used turntables and helped keep vinyl alive throughout the golden age of CDs (late 1980s to 2000). From dance music to scratch and turntablism that was the market that allowed Technics to stay in business, and the products that helped fuel growth in companies such as Numark, Stanton, Denon, Pioneer, and even Audio-Technica. It also helped companies such as Audio-Technica and Ortofon keep developing and manufacturing special cartridges and styli.

With the DJ market transitioning fully to digital, today’s “phono” market is again dominated by a focus on the consumer mid-level segment, with companies such as Pro-Ject Audio Systems, founded in 1991 by one of Austria’s leading high-end audio distributors and genuine music lover, during the onslaught of the compact disc era. Heinz Lichtenegger, the company’s founder and CEO, invested in manufacturing electronic components, including phono preamps, and gradually challenged the common “cost-is-no-object” approach to analog audio equipment that still dominated the high-end/hi-fi market by manufacturing turntables, tonearms, and related accessories at a reasonable price, without compromising build quality or sonic performance. Pro-Ject’s brilliant strategy and state-of-the-art factory in Litovel, Czech Republic, helped create a global company that has licensing agreements with major brands and corporations.

The high-end segment also allowed the revival of classic brands such as Thorens, and inspired all the main audio companies to launch turntables to expand the catalog, some after more than 20 years without a single product in the segment. And Japanese companies Technics and Audio-Technica are now again leading names in the product category, exploring all price segments.

State of the Industry 2022

While the vinyl market is still highly motivated by collectors who still enjoy existing stock of old records—now again available through dedicated retail and online stores—the amount of new pressings of classic catalogs and new music is now significant enough to be characterized as an economic activity. And that’s what is motivating the sales of new turntables and related hardware and accessories.

To understand the size of this market, the just-published “Global Music Report 2022 – State of the Industry,” from the International Federation of the Phonographic Industry (IFPI) provides a very precise overview of the associated content and media formats. In 2021, global recorded music revenues posted growth of 18.5%. This was the seventh consecutive year of global growth, with increased revenues in every region represented in this comprehensive report.

While digital revenues have increased steadily over the past few years and streaming continued to be the dominant format globally, accounting for 65% of global recorded music revenues (total revenues for 2021 were $25.9 billion USD, increasing by 24.3% in 2021), the demand for physical music continues, especially in younger age groups, and represents nearly 20% of the overall music business and growing +16.1% compared to 2020.

By the end of 2021, there were 523 million users of paid audio streaming subscription accounts globally, helping to create a massive $16.9 billion USD market.

With lessons learned from the rise-and-fall of digital downloads, record companies are also now fostering growth by not focusing on a single media channel or format, but by expanding a broader music ecosystem that includes all physical formats.

It’s important not to forget the diversity of the current global music market, with local artists and genres selling much more than they ever did, high-growth across Asia, Latin America, and Africa, and basically all formats remaining viable in all those regions. That even includes the revived music cassette, increasingly used for promotional fan-based campaigns, the CD now growing again globally, and of course, vinyl, which is now clearly established worldwide.

Asia now accounts for a significant share of the global physical revenues (49.6%) with vinyl generating record business as the resurgence of interest in vinyl expanded 51.3%. The two largest markets, US and Canada (an IFPI region) and Europe all grew significantly, with the US market alone growing by 22.6%.

For the first time since 1996, recorded music revenues reached the highest revenue levels this millennium, and both CDs and vinyl records experienced revenue growth in 2021. According to the RIAA’s latest annual report, the resurgence in vinyl records continued for the 15th consecutive year, as revenues grew 61% to $1 billion USD in 2021 in the US alone. The last time vinyl records exceeded $1 billion in the US was 1986. Vinyl now accounts for 63% of revenues from physical formats, and 7% of total music revenues.

A very useful overview of the formats and revenue sources for the music industry is provided by the historical database maintained by the RIAA in its website: www.riaa.com/u-s-sales-database

The Entry-Level Products

Within this framework, we have witnessed significant activity in the audio industry with frequent product launches in all hardware categories. The past two years—with the effects of the global pandemic restricting live entertainment and in-person experiences, and allowing consumers to spend more time listening at home—have enabled increasing sales of turntables and associated products. At the entry level, consumer audio manufacturers are offering “vinyl bundles” or affordable turntable and speaker packages, including wireless streaming to Bluetooth speakers.

An example comes from The House of Marley, the company created in 2010 by the late Bob Marley family, inspired by the possibilities of using eco-conscious audio products in entry-level lifestyle audio products. The House of Marley uses socially responsible materials, including FSC-certified wood, upcycled fabrics, and recycled silicone, plastic bottles, and bamboo, as a greener alternative, while leveraging all the improvements in wireless audio technology for true wireless earbuds, speakers, and even turntables.

The Andover Audio Spin Collection of products and accessories for vinyl fans includes the SpinStand for up to 150 vinyl records, Andover’s own SpinDeck turntable, the SpinBase powered speaker system, and more recently the SpinSub that can fit inside the SpinStand or just be placed on the floor.

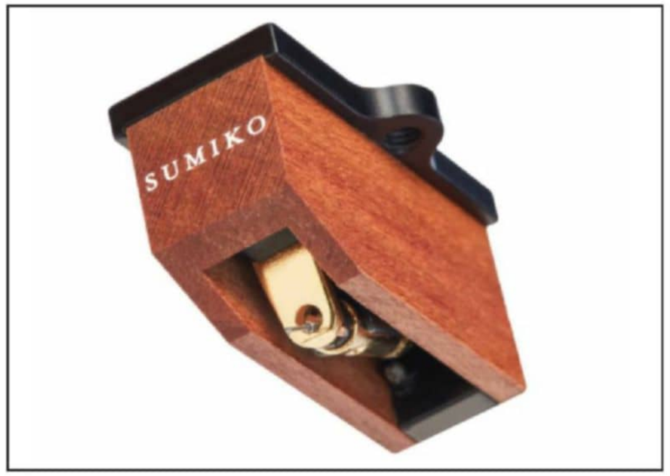
The Debut Carbon EVO represents the epitome of Pro-Ject’s philosophy: high performance, clean aesthetics, and superb value. Combined with a factory-mounted Sumiko Rainier phono cartridge and a low-mass carbon fiber tonearm, the Debut Carbon EVO was an instant best-seller, retailing for $499 USD.

This special-edition Pro-Ject Debut PRO turntable is hand-crafted in Europe and is available in the US with a suggested retail price of $899 USD.

The brand offers Bluetooth speakers with phono inputs, ideal to connect its affordable "Stir it Up" turntables, also available in a Bluetooth-enabled model, both featuring an Audio-Technica cartridge and a unique Bob Marley quote engraved on the tonearm.

At that affordable, entry-level consumer segment, there are currently many great-looking turntable options, such as the 2022 Crosley T160A-GY T160 two-speed turntable with pitch control that features a built-in Bluetooth receiver, pre-mounted Moving Magnet cartridge, and a full-size aluminum platter, selling for just $189.95 USD with matching stereo speakers. An irony considering that modern vinyl pressings of popular music retail at an average price of $35 USD.

The Technics SL-1500C ($1,199.99 USD) uses all the technologies acquired through the development of the SL-1200 Series and the high-end SL-1000R model inserted into the single-rotor, coreless direct drive motor. The aluminum die-cast chassis is rigidly integrated with a special material consisting of ABS mixed with glass fiber to achieve a two-layer construction. The tonearm is a static-balance universal S-shape tonearm, another Technics tradition. The SL-1500C has a built-in phono equalizer amp compatible with MM cartridges and the dedicated power supply for the phono equalizer is isolated from the power supply. The supplied universal head shell is mounted with an Ortofon 2M RED cartridge.



The new limited-edition Celebration 40 phono cartridge was launched in honor of Sumiko's 40th anniversary and is the latest refinement of the award-winning Pearwood Celebration II cartridge with a solid, ultra-low-mass Microridge stylus in a plumwood body.

Of course, users requiring a bit more from their record players will quickly start looking for improved alternatives. An example of a small company that successfully leveraged that entry-level enthusiasts market is Massachusetts-based Andover Audio.

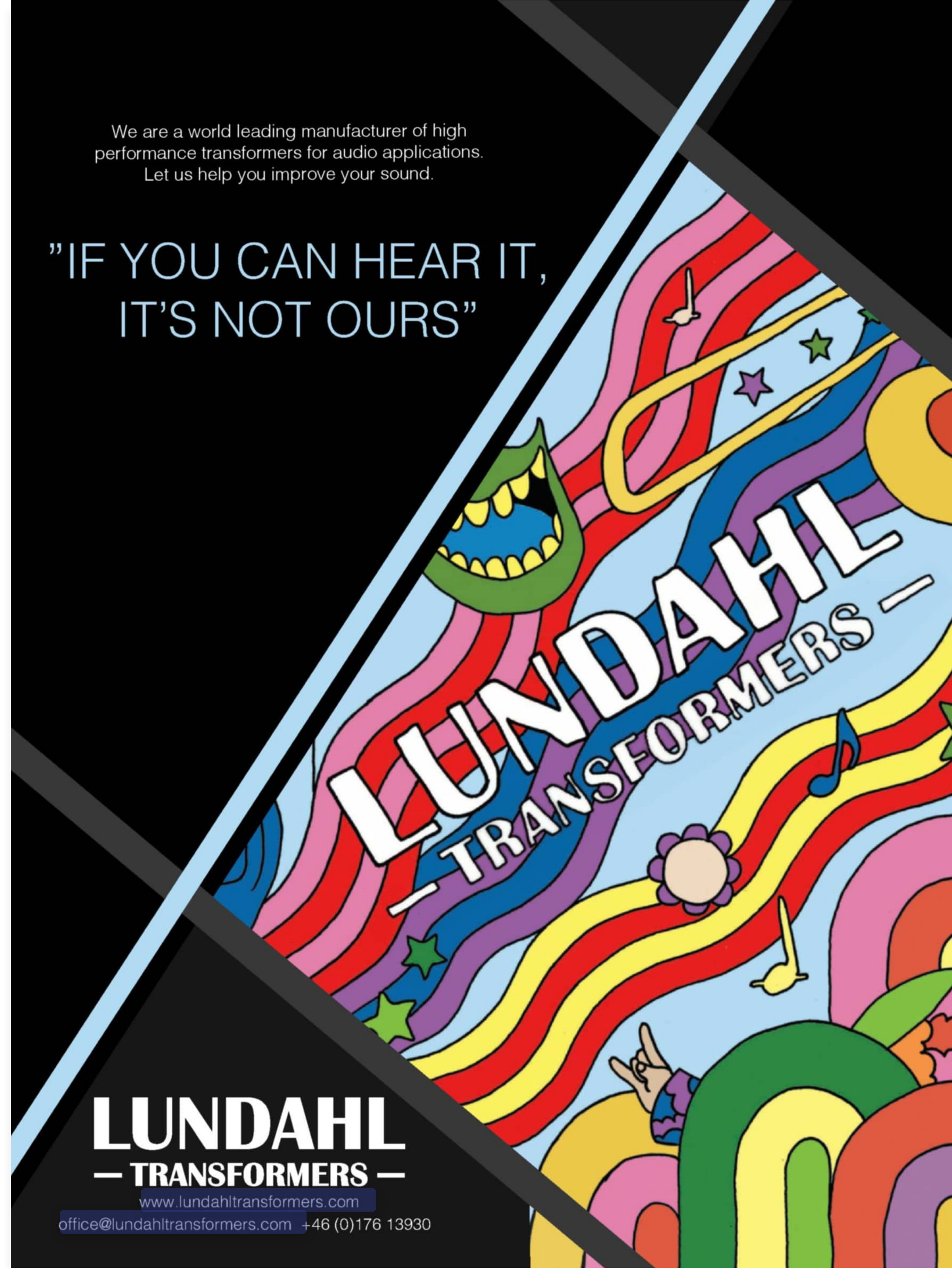
Although Andover Audio only licenses and resell the turntables at the center of its business, it created a business in the vinyl space around its "Spin" product system. In 2019, the company created the Model One Record Player integrated audio system, combining a custom turntable based on the Pro-Ject Debut Carbon Espirit SB, directly over a high-grade audio speaker system with integrated streaming capabilities. In 2020, Andover launched the Spinbase, a streamlined version of the Model One speaker solution for under-turntable placement, fitting basically any turntable. It also continued to sell its Spinstand Record Stand to create a self-standing system with the Spinbase, and later added the SpinSub active subwoofer that recreated the convenience of the original Model One system, with a versatile full-range listening solution.

Andover, as well as similar companies in the US, Europe, and Asia, haven't even attempted to get into the turntable business. Mainly, because they just need to bundle and resell existing products from companies such as Pro-Ject or Clearaudio. With the Model One Record Player, Andover offered a custom Pro-Ject Debut Carbon Espirit SB turntable with an Ortofon OM2 Silver cartridge, a carbon fiber tonearm, and acrylic platter, delivering the ease-of-use that quality-conscious entry-level user's desire, with the flexibility that advanced listeners want. To match its Spinbase, Andover now offers the Spindeck, an affordable belt-driven turntable, custom designed by Pro-Ject for Andover.

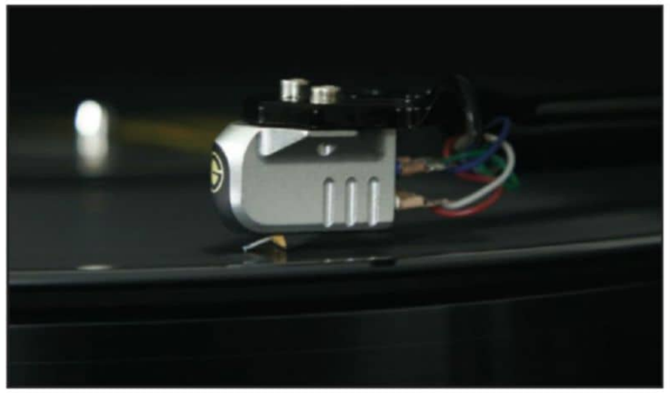
A great demonstration of the way Pro-Ject Audio Systems dominated the segment is given by the brand's own Debut range of turntables, which after 20 years, became one of the best-selling products in the history of hi-fi, with more than one million units sold. In 2020, Pro-Ject launched the Debut Carbon EVO (for Evolution), an updated and refined version of the original turntable design, featuring the brand's famous one-piece carbon fiber tonearm technology, electronic speed selection, suspension elements from the EISA award-winning X1 turntable, and a factory-mounted Sumiko Rainier phono cartridge.

Increasingly working with cartridge maker Sumiko in the US market, Pro-Ject also launched the new Debut PRO 30th anniversary turntable, retailing for $899 USD, and featuring a pre-adjusted Sumiko Rainer cartridge and one-piece carbon/aluminum tonearm. The Debut PRO is a precision belt-drive turntable with electronic speed control in a MDF chassis, featuring a heavy-duty, nickel-plated machined aluminum bearing block, allowing the tonearm to track precisely across the entire surface of the record, over a die-cast aluminum platter with integrated TPE damping. New to the Debut series, the tonearm height and azimuth are both adjustable, allowing for the use of a wide range of cartridges.

More recently, Pro-Ject also launched the A1 Turntable, bringing back automatic turntables for a new generation of vinyl enthusiasts, making the whole experience even easier and simpler for new users. The Pro-Ject Automat series of turntables includes a factory installed and aligned Ortofon OM10 cartridge, an 8.3" aluminum low-mass tonearm, and a built-in, switchable phono preamp.



Ortofon was established in 1918 by Danish engineers Axel Petersen and Arnold Poulsen. Now Ortofon is a micro-mechanical powerhouse, which develops and manufactures hearing aid components and phono cartridges for vinyl records. In 2021, Ortofon expanded its Exclusives Series of high-performance moving coil cartridges with a new flagship model—the MC Verismo. Meeting a growing market for premium cartridges, the new Ortofon Verismo is made of titanium and uses Ortofon's Replicant 100 diamond stylus and solid Diamond cantilever.



With more than 100 years of rich heritage, in 2020, Goldring announced the Ethos moving coil cartridge that combines a top-quality diamond stylus, and aluminum alloy cantilever, with Goldring's hand-built GOL-1 moving-coil generator.

In 2020, the revived Thorens company introduced the TD124 DD, an evolution of its TD124 turntable, representing the pinnacle of 21st century turntable design, available in the US in a limited 120V edition, at an MSRP of $14,000 USD, including a Thorens SPU TD 124 phono cartridge, a TP 124 tonearm, a piano black plinth, a custom flight case, and a signed Certificate of Authenticity.

The Hi-Fi Turntables

Another clear market trend that resulted from the consistent growth in vinyl record sales was the return of classic hi-fi brands with new turntable models at different price segments, while Technics and Audio-Technica also responded with more models to defend their positions. At the same time, the market has witnessed the return of some legendary names.

The revival of Thorens (now as a company based in Germany) and the introduction in 2020 of the TD124 DD, an evolution of its popular TD124, one of the most renowned turntables in consumer electronics history, was a significant event. An homage to the original TD124, the new TD124 DD combines the beauty of the original design with state-of-the-art technology, updated components, cutting-edge materials and unique design flourishes.

Side by side with the Elektromesstechnik (EMT) 930, upon its introduction in 1957, the original Thorens TD124 turntable immediately became THE reference standard for both professional and home applications, and both models have been used for decades in broadcast studios around the world. (Thorens, together with Studer/Revox, distributed the EMT turntables, and EMT later adopted the Thorens tonearm and belt-drive design for its EMT 928 consumer turntables.)

With time, music lovers from all over the world recognized the superior performance of the TD124, and an enthusiastic consumer base remains devoted to that turntable design to the present day. In 2020, Thorens honored this tradition with the all-new TD124 DD, where a height-adjustable aluminum chassis now rests on vibration-damping elastomer elements whose viscosity is identical to the original's rubber "Mushroom" isolators. Instead of the idler wheel and belt-drive system employed in the original, the new TD124 DD uses a 12-pole "High Precision" Direct Drive motor with Delrin bearing mirror (thrust plate).

Like the turntable, the new TP 124 tonearm is an aesthetic reproduction of the EMT tonearms often fitted to original 124 models.

The TD124 DD also comes with a second, heavier counterweight that matches the Thorens SPU TD 124 pickup, which is included in the TD124 DD North American Edition. The SPU 124 is an updated version of another legendary piece of vinyl equipment: the famous Ortofon SPU Phono Cartridge, created in collaboration with Ortofon.

Traditional British hi-fi brands are also entering or re-entering the category after decades. Even in cartridges, as UK-based Goldring, one of the world's leading manufacturers of phono cartridges and an industry standard for electro-magnetic pickups, now returns under the management of Armour Home Group (Q Acoustics). With more than 100 years of rich heritage, Goldring still offers a range of moving magnet, moving coil, and moving iron cartridges, together with stylus and vinyl cleaning kits.

Also in the UK, Cambridge Audio has announced two new turntables—the Alva TT V2 and the Alva ST—one being a direct-drive design and the other a belt-drive, priced at $1,999 USD and $999 USD, respectively.

Unveiled at CES 2022 in Las Vegas, NV, the new Alva turntables build on the success of the company's previous Alva TT turntable launched in 2019 as the world's first turntable with built-in aptX HD Bluetooth.

Targeting the modern vinyl lover who doesn't yet have other components except maybe an amplifier and a pair of speakers, the Cambridge Audio Alva TT V2 turntable is an upgraded next-generation model, while the ST enters the company's range to provide further choice and flexibility. Both models are ready to be plugged into any line level input in amplifiers or active speakers, since both models feature a built-in phono stage based on the company's prized Alva Solo and Alva Duo phono pre-amplifiers.

Naim Audio has also placed considerable resources to design a very sophisticated vinyl reproduction system. The result was the Naim Solstice, the first turntable in the British brand's almost 50-year history, launched in 2021. It comes with a next-generation version of its own Naim Aro tonearm, an Equinox MC cartridge, external Solstice Series Phono Stage, and a dedicated power supply unit. The Solstice Series NVC TT phono stage and NPX TT power supply are hand-built by Naim in Salisbury, UK, while the NVS TT turntable, Aro arm and Equinox cartridge are manufactured by Clearaudio, the Erlangen, Germany-based turntable specialist. This turntable was also offered as an exclusive collector's item and a commemorative product for those devoted to the British brand—now part of the Vervent Audio Group since its merger with Focal-JMlab in 2011.

In the US, Harman's Mark Levinson recently unveiled an expanded line of 5000 series products that also includes the Mark Levinson Nº5105 turntable, built upon a nearly 2" thick, solid aluminum plinth. While all the Mark Levinson 5000 series are designed and manufactured in the US, the 5105 turntables are contract-manufactured in Germany. The iconic Mark Levinson hourglass knob design features as a record weight—bead-blasted machined aluminum with a gently curved profile mass-loaded with solid brass. The tonearm tube is 10" high-gloss back carbon fiber fused to a solid aluminum headshell. The 12V synchronous motor's control signal is digitally generated to eliminate temperature drift and ensure speed stability and low wow/flutter.

As vinyl is trending, turntable options are also expanding in every price segment and we couldn't close this market update article without mentioning the Bang & Olufsen initiative of resurrecting its iconic Beogram turntable with an automated tangential tonearm, now on the Beogram 4000c Recreated Limited Edition. This turntable, originally introduced in the early 1970s, is the first product to

The Naim Solstice Special Edition turntable features a magnetic bearing supporting a high-mass, highly polished aluminum platter, with a unique, self-calibrating motor drive system, retailing for $20,000 USD. The limited edition set is complemented with a Naim Equinox MC Cartridge featuring a microline stylus shape with a boron cantilever, a stiff-but-light design that faithfully transfers the stylus movements to the moving coils.

be released in the company's new Classics initiative: Restoring and reimagining classic products to demonstrate Bang & Olufsen's capabilities and design principles that can extend the lifespan of future products.

Bang & Olufsen identified 95 units of the Beogram 4000 series turntable and brought them back home to Struer, Denmark—to the same facility where they were first created nearly five decades ago. The turntables were then disassembled and thoroughly inspected by a team of skilled engineers. Once this process was completed, each Beogram was individually tested then fine-tuned to meet Bang & Olufsen's exacting specifications, before being reintroduced in the market to be enjoyed for decades to come. Each turntable is fully restored, uniquely numbered and comes with a five-year warranty. To complete the experience, each turntable comes in a crafted solid oak box with aluminum details.

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Orchard Audio Starkrimson Stereo Ultra

Pushing Power Amplifier Performance Boundaries

By
Stuart Yaniger

Photo 1: The Orchard Audio Starkrimson Ultra has a simple and functional appearance.

What if someone took GaN Systems' gallium nitride (GaN) power transistor technology, which Stuart Yaniger evaluated for *audioXpress* in the April 2022 issue, and designed an actual audio amplifier for the best possible high-fidelity results? That's precisely what Leo Ayzenshtat, the founder of Orchard Audio, did with his Starkrimson Stereo Ultra audio amplifiers.

In my previous article on GaN Systems' gallium nitride (GaN) power transistor technology, I hinted that the already very good performance of its reference design could be made even better as a pure power amplifier. Of course, the reference design is absolutely good enough to be transparent to human hearing and likely incapable of audible improvement, but engineers will always take a good thing a step further. Using the same output devices, but doing the control and feedback differently, it would seem possible to make things measurably more perfect, and without incurring ridiculous costs.

Photo 2: The input and output connections are high quality and well laid out.

Last year, I wrote about Orchard Audio's earlier Class-D power amplifier, the BOSC, later renamed Starkrimson (see Resources). The performance was excellent, and the monoblocks ran cool and silent. The company's principal, Leo Ayzenshtat, has now updated the circuit, increasing both power and measured performance, using GaN Systems' High Electron Mobility Transistors (HEMTs) as output devices. Orchard was one of the early adopters of GaN technology, and as new and improved devices from GaN Systems became available, Orchard again became one of the first to take advantage of the advances in this fast-moving technology.

The Ultra is available either as amplifier modules for use in active speakers or DIY projects, or as a packaged stereo amplifier. The review sample used a prototype box, but other than appearance, it was identical to production units now shipping. It's pretty plain: The front panel has the Orchard logo and an illuminated push-button power switch (**Photo 1**). The rear panel has an IEC power connector, either unbalanced (RCA) and balanced (XLR) inputs, and heavy-duty binding posts for speakers (**Photo 2**). Note that this photo is from an earlier version; the packaged amp is supplied with either RCA or XLR inputs, rather than having both. The binding posts appear to be the same ones I've seen used on other high-quality equipment (e.g., the M10 and the M33 from NAD), which are sturdy and very easy to use with a variety of connection options.

As with the earlier BOSC amps, the amplifier modules are neatly laid out, well-constructed, and surprisingly compact for the rated power (**Photo 3**). During use, the amplifier always ran cool and was absolutely unobtrusive. If there were any electromechanical noises, they were fully attenuated by the box.

From a design perspective, Orchard departed significantly from GaN Systems' reference design. Orchard used its own controller, similar to the one used in the BOSC/Starkrimson, coupled with a Silicon Labs Si8244 driver chip. In any switching amplifier topology with bi-polar supplies, the bottom field-effect transistor (FET) sits on the negative power rail, in this case, -40V. Since the modulator and all other circuitry are referenced to ground, the PWM signal needs to be level shifted down to -40V. This requires some care. The Si8244 chip is isolated from input to output and effectively takes care of this level shifting function as well as being a gate driver.

The GaN Systems' EZ Drive circuit (see Resources) is used to provide the proper drive voltages to the GaN Systems output devices. Orchard's circuit is fully differential, and in contrast to the GaN Systems reference design, there are feedback loops taken from both sides of the output inductor (**Figure 1**). This could reduce both distortion from the inductor (see Resources) and reduce the load dependence of the frequency response. Orchard also believes that higher switching frequencies are advantageous to performance and exploit the higher speed capabilities of the GaN output devices, so they take advantage of the lower gate charge and higher mobility of GaN output transistors compared to conventional silicon MOSFETs. The GaN Systems devices were chosen for the Ultra for ease of assembly and a reliable supply chain.

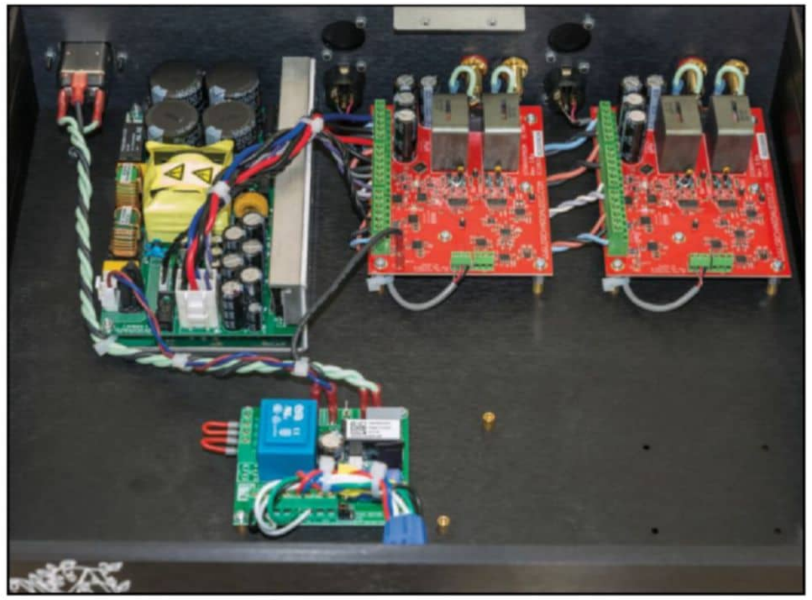


Photo 3: The amplification modules are compact and easy to integrate into custom amps or active loudspeakers.

The Starkrimson Ultra In Use

Before running bench tests, I put the Ultra in my bi-amped system for a few weeks, alternating it between the midrange/treble section and the bass section of the speakers, driven respectively by the preamp or subwoofer outputs of the NAD M10 I use for my main system. Not unexpectedly, it seemed to sound no different than the NCore and the Purifi amps I normally use, which is a high compliment—clean, quiet, unstrained, tonally neutral, exactly what a power amp should be. In fact, when used for the upper section, I could play my system noticeably louder before onset of noticeable distortion because of its higher power capability than the M10's NCore amplifiers. It was also dead quiet: when no music was playing, with my ear right up to my speakers, I could hear… nothing.

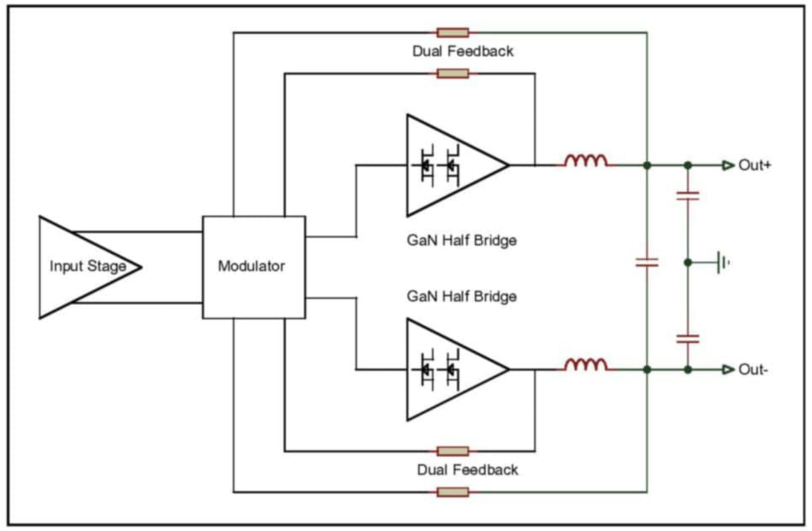


Figure 1: The Starkrimson Ultra continues Orchard's use of fully differential topology, and uses feedback taken from both sides of the output RC network.

I can't comment much on how the amp acts in overload since, although most music I listen to is acoustic, even playing my favorite heavy metal music, I couldn't coax the amp into clipping. Despite some, um, vigorous volume levels, the Ultra remained cool and collected (literally). My speakers have a sensitivity of about 87 dBSPL/2.83V, so if yours are that sensitive or better, the amp will not run out of gas. I'm lucky that none of my neighbors complained to the police.

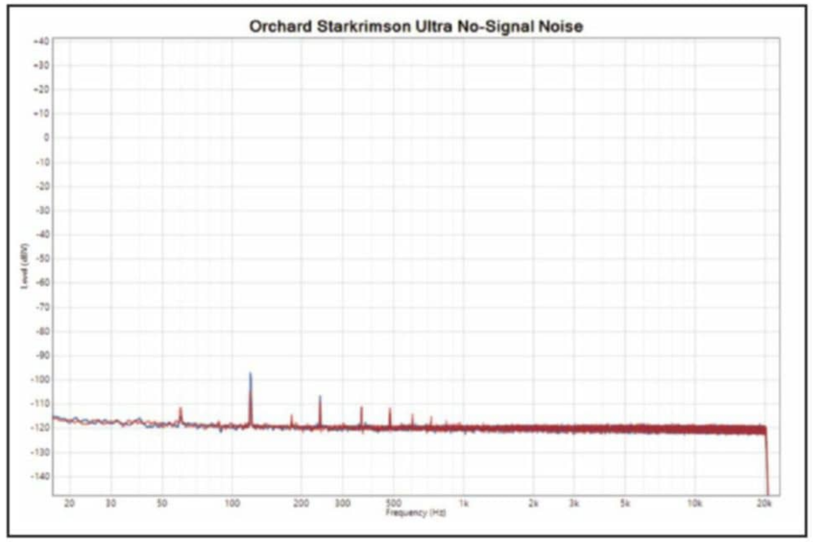


Figure 2: The noise spectrum in the audio band with no signal shows a very quiet output.

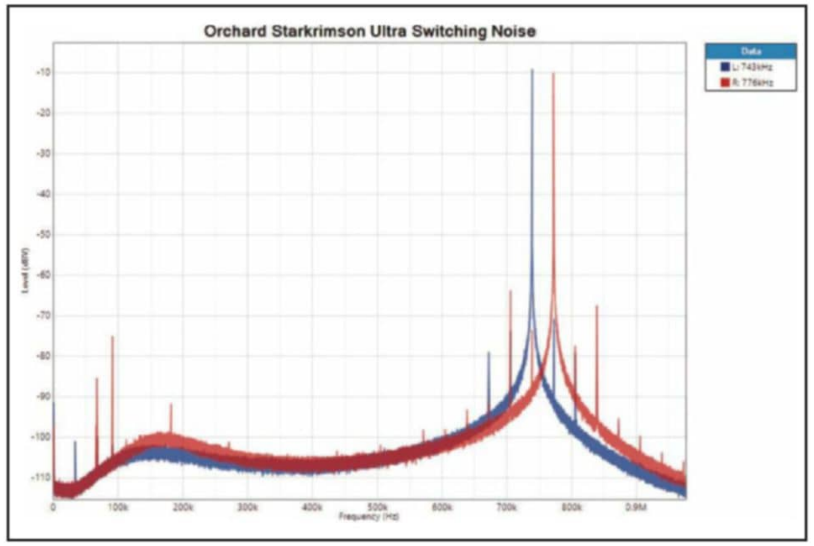
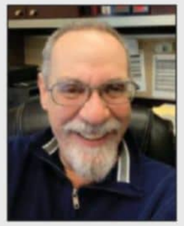


Figure 3: The wideband noise spectrum shows some minor ultrasonic noise and the relatively high switching frequency.

About the Author



Stuart Yaniger has been designing and building audio equipment for nearly half a century, and currently runs a technology consulting agency in western New York. His professional research interests have spanned theoretical physics, electronics, chemistry, spectroscopy, aerospace, biology, and sensory science. One day he will figure out what he would like to be when he grows up.

After testing and living with several excellent examples, I should stop being amazed at how delightfully nonobtrusive modern Class-D amps are, but having grown up in the tube era, and then spending years with large solid-state Class-A and Class-AB amps, it's still a delight.

Test Results

Once the basic functioning was confirmed (at great personal sacrifice to me—having to spend hours enjoying my favorite albums), I moved the amp to the lab bench. As usual, the test gear used here included an Audio Precision APx-525, several homemade dummy loads comprising non-inductive power resistors bolted to heatsinks, NHT two-way mini-monitors, and an HP 3466A precision multimeter.

The bench testing showed what Orchard's optimization of GaN technology could accomplish. First, the basics, starting with noise. Consistent with my in-use observations, the Ultra measures very low noise. **Figure 2** shows the noise spectrum in the audio band, with the AES17 filter in place. There's some small spikes at harmonics of 60Hz, a bit worse in one channel, but the very worst one was a 120Hz spur in one at -97dBV in the worse channel. To put that in perspective, if I had very efficient horns at 100 dBSPL/2.83V, the noise from that channel would be right at the absolute limits of human hearing in a perfectly quiet test chamber, and 20dB to 30dB below the noise of a very quiet room.

Opening up the frequency range and removing the AES17 filter, we can see from **Figure 3** that the noise level is higher in the ultrasonic range, though of no audible consequence. There are some spikes reaching the tenths of millivolts, but these are frequencies at which tweeters are not likely responding, and even if they do, it's at levels that bats would strain to hear. The dominating part is the switching frequencies, which indeed are double the frequency of the GaN Systems' reference design and are just below and above 750kHz. Their no-signal level is roughly 300mV, but this is at AM broadcast frequencies and will not bother any loudspeaker, assuming they can even get past the inductance of typical speaker cables, not to mention the inductance and stray capacitance of loudspeaker voice coils.

The most important aspect of amplification is frequency response. Class-D amplifiers have a bit of a hill to climb there because of the interaction of the obligatory output LC network with the (usually reactive) load, and it's not uncommon to see significant frequency response errors. The Ultra's feedback scheme should, in theory, reduce this effect since part of the feedback is taken from the load side of the output network. **Figure 4** compares the Ultra's frequency response into an 8R resistive load versus an actual loudspeaker. For the 8R load, the response has a rise of under 0.1dB at 20kHz (note the highly expanded scale in this graph). Substituting a loudspeaker load, the deviation increases to slightly under 0.2dB, the audibility of which is highly dubious. This was also lower than the same deviation of the GaN Systems demo amplifier, likely due to the extra feedback loop.

Inextricably intertwined with frequency response is source impedance, which can cause response deviations when interacting with loudspeaker loads, which are far from constant with frequency and far from pure resistance. Because of some incompatibilities with the newest versions of the Audio Precision software, I was unable to use their excellent source impedance utility, so I did a few spot measurements using the change in output voltage with the change in load to determine the Thevenin equivalent impedance. At 5kHz, the source impedance was 24mΩ, an excellent value; for those more accustomed to the damping factor spec, this is equivalent to over 300. Generally, source impedance rises with frequency as the open-loop gain decreases, reducing feedback. The Ultra is no exception, with the 20kHz source impedance being about 100mΩ (damping factor of about 80).

Of course, given the nature of Class-D output filtering, these values are a bit naïve since they do not take into account the reactive nature of the impedance. This is one of the reasons we see a minor rise in response rather than a fall. Nonetheless, the amplifier will not be the limitation here since for most speaker cables of normal length, their impedance will swamp the amplifier's source impedance.

Next, I examined the distortion and the power performance. **Figure 5** shows the 1kHz THD+N versus power for an 8R load. The dominant component is noise up to about 30W, with the actual distortion being well below 0.001%. Note that one channel has significantly worse distortion performance than the other. This was a bit puzzling since this exact measurement had been done on this amp using the same models of test gear that I use, and the excess distortion in that channel had not appeared. To be clear, the excess distortion was still far below any plausible audible threshold, but it was still a bit odd. In the past, Leo Ayzenshtat's

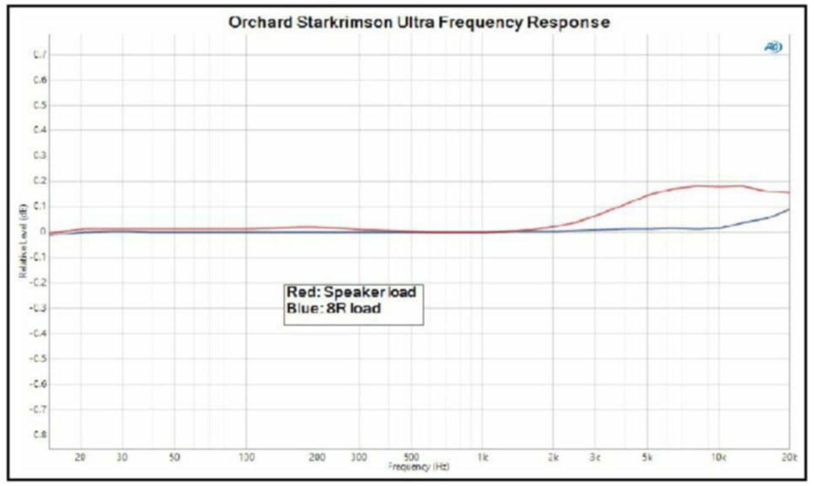


Figure 4: The frequency responses of the Ultra into a resistive load and a loudspeaker show a very minor rise in the top octave. Note the highly expanded scale.

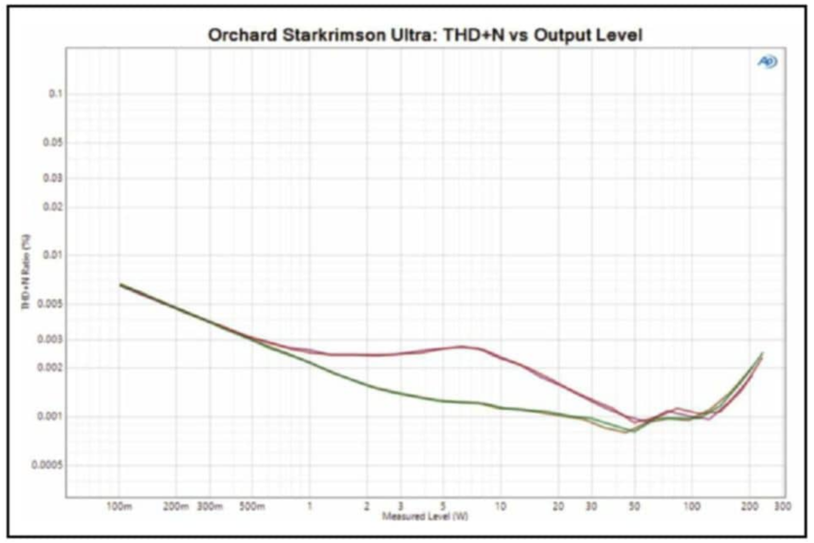


Figure 5: The Ultra's undistorted power easily exceeds the specification. See text for discussion of the channel differences.

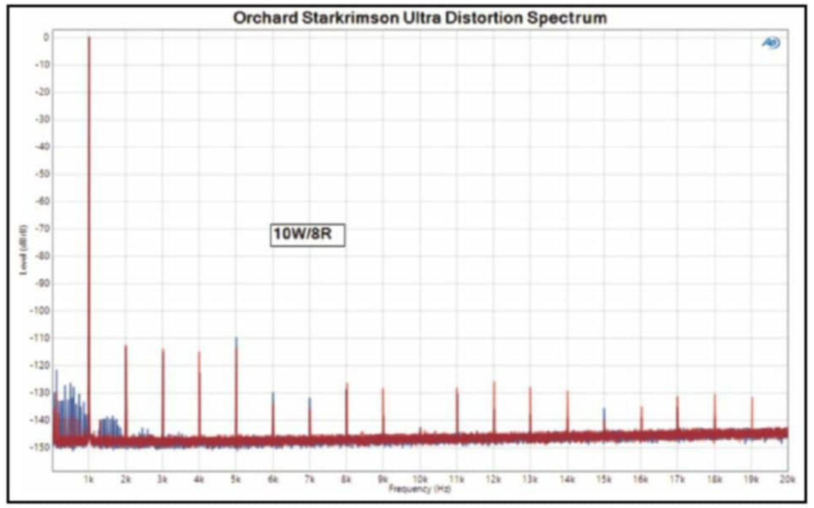


Figure 6: The harmonic distortion spectrum shows that all the high-order products are extremely low level.

measurements and mine have tracked almost perfectly, which deepened the mystery. One more clue emerged when I repeated the measurement several times over the course of several days and observed that the worse channel's performance varied from measurement to measurement; Figure 5 shows the largest variation that I saw.

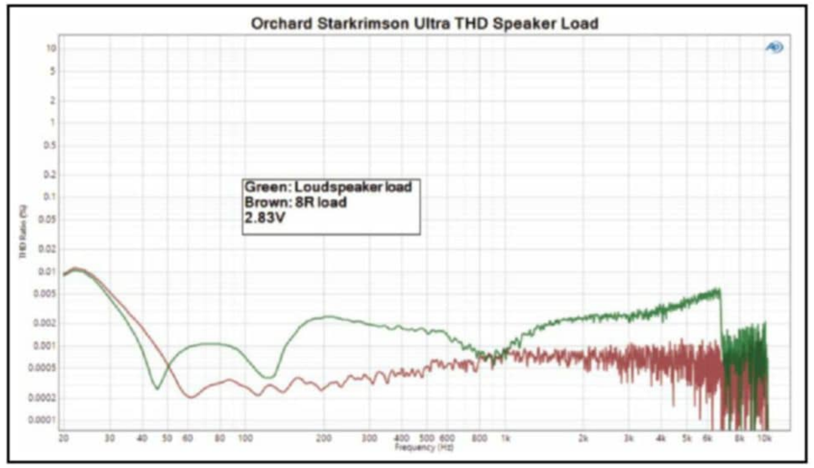


Figure 7: The dependence of distortion on frequency is quite low, even with a loudspeaker load.

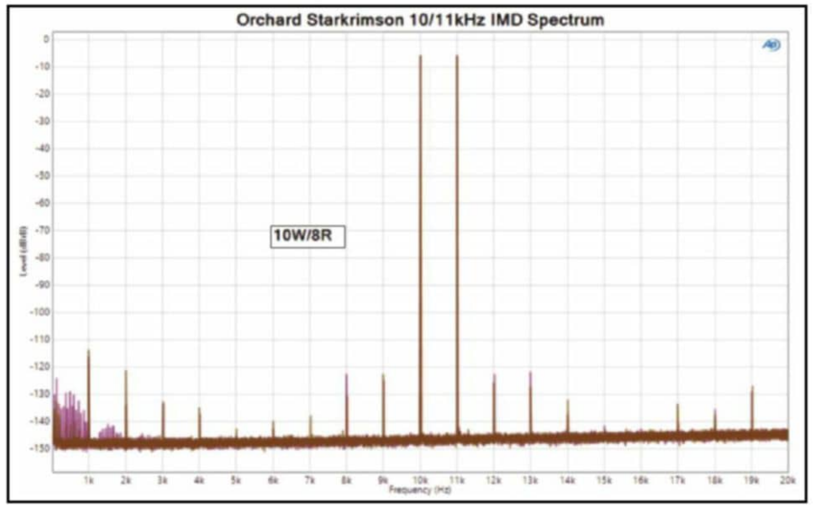


Figure 8: Intermodulation distortion with a 10kHz and 11kHz tone shows excellent linearity.

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When I returned the unit to Leo for analysis, he confirmed my observation and immediately dug in to determine the cause. As I had mentioned in my review of the original Starkrimson nee BOSC, Leo's day job is PCB design for mission-critical aerospace, so he was perfectly positioned to direct the failure (in a relative sense) analysis. It turned out that, as he and I speculated, a microscopic defect had appeared in one of the solder joints due to the vicissitudes of shipping. This is the only review unit and it had been sent back and forth numerous times, so it experienced mechanical stresses far beyond normal. Nonetheless, he used this as an opportunity for improvement, and has modified the PCB processing and inspection to eliminate the possibility of this happening even under repeated abuse by shipping companies. And again, I need to qualify that this is a defect that would only have been evident on careful testing with top equipment—not something that would be noticeable in normal use (and indeed, it was no issue in my use of the Ultra in my audio system).

In any case, the distortion at the rated power of 250W was under 0.003%, and there was no sign of clipping until nearly 300W. Switching to a 4R load, similar results were obtained with a clipping point of over 500W with both channels driven. This caused my lab circuit breaker to trip, which ended the measurement quickly!

The harmonic distortion spectrum at 10W into 8R is shown in **Figure 6**. The very low noise floor exposes the long string of harmonics. But note that their level is exceptionally low—the worst is the fifth at less than -110dB below the fundamental. This is very close to challenging the capabilities of the AP analyzer and is extremely unlikely to have any audible consequence.

The dependence of THD+N on frequency is shown in **Figure 7**. This was acquired using a Farina log-chirp sweep. At 2.83V with an 8R load, it is remarkably flat, indicating a very effective feedback scheme—as with source impedance, one usually sees a significant rise at higher frequencies due to the reduction in feedback from falling open-loop gain. That is not evident here, and it is likely that the "N" part is what is dominating. The other trace in Figure 7 is the same measurement, but substituting the loudspeaker load. This does not seem to ruffle the Ultra at all, and again, it is likely that the noise is a large factor, given that the speaker has many physical inductances and capacitances in it, perfect to act as an antenna for noise pickup.

I checked the 10kHz/11kHz intermodulation distortion (IMD) at 10W into a resistive load (I was not going to torture my speakers and ears with this), with the results shown in **Figure 8**. The main IMD product at 1kHz is at -115dB, with sidebands at -125dB, which is ridiculously good and once again pushing the limits of the AP analyzer.

What about more complex signals? I used a 30-tone composite signal, which not only contains multiple sine wave components, but has a much higher crest factor (13dB) than the sine-based Farina sweep (3dB). With a loudspeaker load, the spectrum of **Figure 9** resulted at the equivalent of 1W average power. The noise and distortion products (the hash between the tones) was at its worst 90dB below the level of any of the individual tones, and more than 100dB below the 2.83V sine wave equivalent reference level.

All in all, the bench performance is flawless, correlating with the listening impressions.

Conclusions

In my article on the excellent GaN Systems demo amp, I speculated on what the performance using its technology would be for an amp designed for top performance rather than as a multifunctional utility. This answered my question—the performance was outstanding. As good as the original Starkrimson was, the Ultra shows similar high performance, but with higher power. Both in use and on the bench, the Ultra was an exemplar of modern audio power amplifier technology, and could easily be an end-game for upgraders.

The availability as modules can enable hobbyists and small manufacturers to customize packaging, build custom multichannel units (or monoblocks), and integrate amplification into active speakers. Lots of superbly distortion-free power in a tiny, cool, and customizable package or prepackaged in an unobtrusive stereo amp. How can you go wrong?

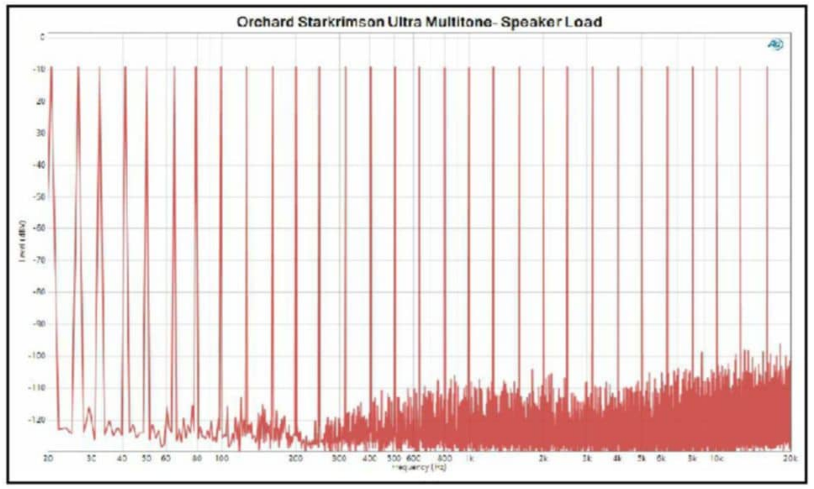


Figure 9: Multitone analysis with a loudspeaker load shows very little grunge.

Birds of a Feather

Western Electric's New Production 300B

By
Michael Boele

This is the highly anticipated long-term review of a pair of 2021 new production 300B directly heated power triodes made in Western Electric's production facility at Rossville, GA. Michael Boele received a pair to test at the end of March 2021, and has been extensively using them since they arrived.

Photo 1: A view of the Western Electric 300B 2021 Rossville production tubes as they arrived to me in the box.

I shall neither talk much about the history of the company Western Electric (WE) in general nor about the lore surrounding the electron tube-type 300B, be it the "original" or the various copies/clones/reissues, as these topics have been the subject of many articles. For readers interested in learning more about the background of Western Electric and 300B tubes, I recommend the excellent articles by Peter van Willenswaard "In Search of the Perfect 300B Tube" [1], and by the late J. C. Verdier, "Kinky Triodes – 300Bs Investigated" [2]—both are available on the web.

I shall focus solely on the 2021 production Western Electric 300Bs and their behavior and quality—comparing them a bit to older "Western Electric originals" and to some third-party 300B clones. With that said, my review shall begin with my journey into the 300B and single-ended triode (SET) amplification world.

My Experiences with Tubes

I have been using electron tubes for audio amplification since my early youth in the 1970s, beginning with amplifiers built from the leftovers of tubed radio receivers, TV sets, and other electronics from scrap yards or surplus sales. Then, I graduated to more ambitious projects with higher quality components and less random circuits. Over time, I have designed, built, and measured many amplifiers and topologies, vacuum tube, hybrid, and solid state, both small signal and power, from microphone amplifiers to kilowatt (kW)-power modulation amplifiers for AM transmitters. Most of the time, I have used solidly engineered circuits with negative feedback (NFB) and other measures to keep amplifier behavior stable and tolerant to component tolerances and aging, and to ascertain good measured parameters. Eventually, I have learned that while measurements give an idea on the technical performance of amplifiers and their behavior in specific situations, the best measured amplifier is not always the one that sounds most pleasant and engaging—through that I came across the return to "simple" single-ended amplification driven first by Japanese audio enthusiasts,

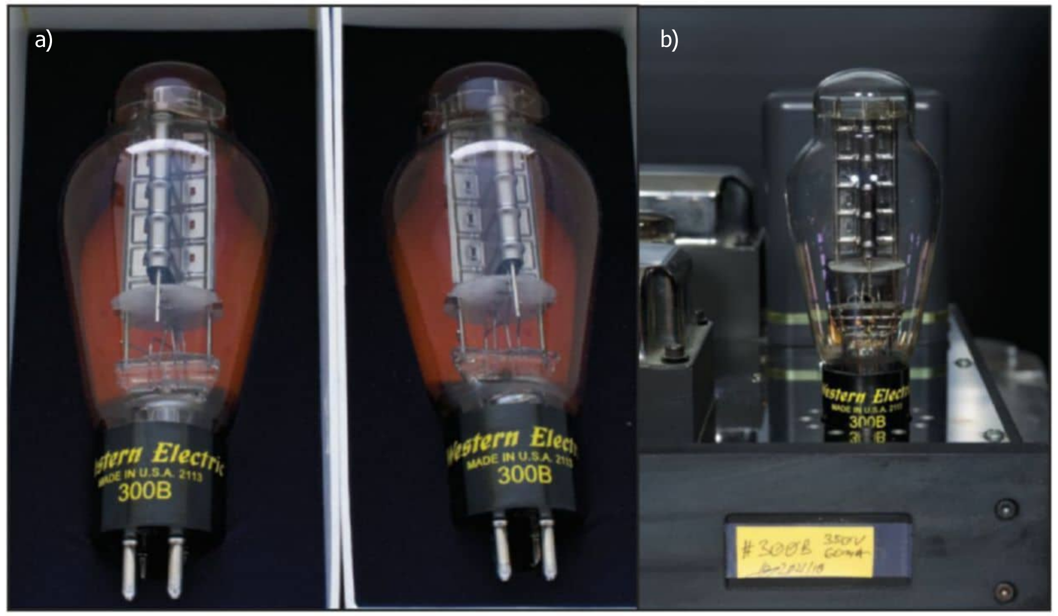


Photo 2: Here are the Western Electric 300B 2021 Rossville production tubes unboxed (a) and in an amplifier (b).

spilling over to the US and Europe. In the 1990s, I had the chance to listen to a number of systems using such amplifiers, and while the sound of many of these systems did not agree with my taste, others did, and to a degree that I found worthwhile to investigate. In 1999 I came across Jean Hiraga's book *Initiation aux amplis à tubes* [3], and, following that, started to build single-ended amplifiers with the 300B tube.

Initially I copied circuits from the magazines and the Internet, using "cheap and cheerful" Russian and Chinese 300Bs, quickly finding that I did not like these amplifiers as much as some that I had heard elsewhere, or my "conventionally engineered" push-pull and OTL amplifiers. But then, after positive listening experiences with some other enthusiasts' systems, I decided to dig deeper, and try and measure other driver topologies and "better" 300Bs.

Over time, I built up quite a collection of 300B tubes (Chinese, Russian, Czech, and Slovak clones of "improved" versions, as well as several pairs of Westrex Western Electric reissues produced in the Kansas City factory in the late 1990s, and two "old stock" WEs traded for some West German broadcast amplifiers), and tested them extensively. The tests confirmed the findings found in J. C. Verdier's article—many samples in the market are of rather inferior quality and have a much shorter service life than those rated for the WE "Originals."

By 2008 I had developed a "reference" amplifier topology, which delivered the sound and measurement results I had been looking for, naming it the "MB300+," as it could as well accommodate a range of other directly heated triodes. I found that, when demonstrated at amateur audio events, the amplifier did perform quite well in comparison to other amateur and some commercial products available for direct comparison. In 2009, during the European Triode Festival, I presented measurement results of various 300B clones and originals in this amplifier and allowed comparative playback of music. At the festival, the Westrex WE 300B reissues from 1999 were rated highest by the audience. The listening results interestingly did correlate well with Peter van Willenswaard's 1999 findings—second rated were Czech "boutique" 300B clones, which I actually favor myself. At that time, and after the factory move from Kansas City, MO, to Huntsville, AL, the supply of Westrex Western Electric 300B clones had all but dried up—forcing people to look for alternatives.

Since 1999, high-grade clones from China and other places have entered the market, some of them allegedly close to the original Western Electric or 1990s Westrex Western Electric production, but despite the high price, in general they do not meet the lifetime expectation of the WE originals (rated for 40,000 hours at my favored operating point). Users who wanted to stay with WE original products were forced to take the risk and purchase new-old stock (NOS) at very high and ever-increasing prices, which were not backed by factory warranties any more; or they could use stock they still had, as long as it lasted—like me, sparingly using my old stock samples acquired in 2001.

So, when I learned that a new production facility had been set up in Rossville, and production had restarted using the old construction diagrams, 1962 recipes for the cathode chemistry, and new/updated machinery and test equipment, I thought this to be good news, but was a bit skeptical about the chances for success—setting up a proper production of vacuum tubes is difficult. Refer back to the J. C. Verdier article and the problems outlined in there for more detailed information.

The WE 300B Tubes

In March 2021, *audioXpress* asked me if I would like to review a pair of tubes from the Rossville production and rate them in comparison to the old ones. Understandably, I was quite enthusiastic about that request, and said yes right away.

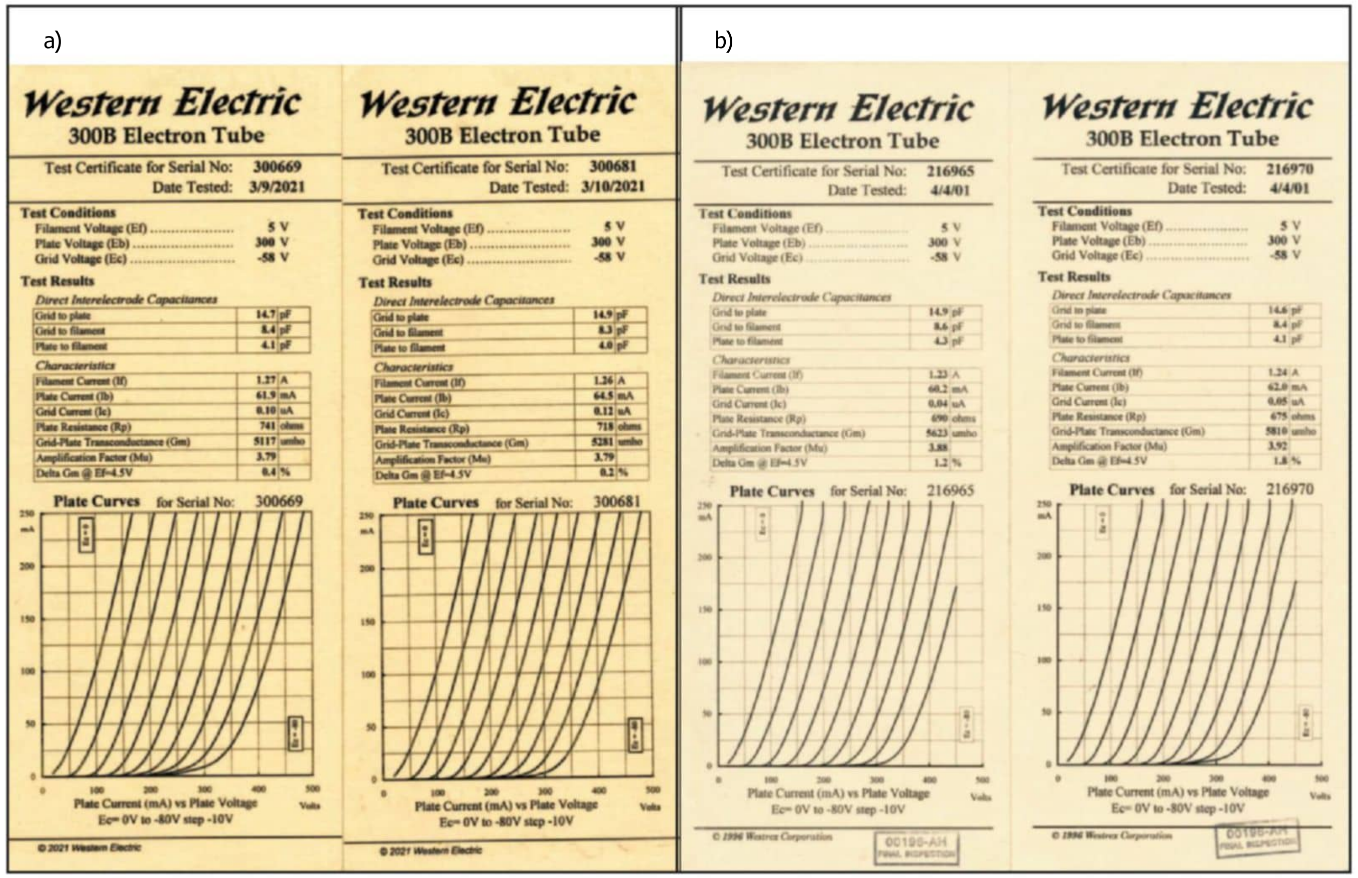
For me, it was immediately clear that I needed to critically assess if the new production samples met the expectations one would have for such products, which, with the WE name, and backed by a five-year warranty, still command a rather high price.

So I set up a test plan—get them, burn them in in same way the 1999 production samples had to be burned in (see Peter van Willenswaard's article on the need for burn-in and the justification for it), testing and measuring them during the process—and keep running them for as many hours as possible afterward to glean at the long-term stability of the characteristic parameters.

After getting the tubes out of Dutch Customs in early April 2021, I carefully unpacked them. They came well packed, a bit like Matryoshka dolls, with several layers of cardboard and bubble foil covering a small cardboard box that contained a wooded box that in turn contained two cardboard boxes with the actual WE 300B tubes inside, with matching foam inserts to properly protect them, and ancillary documentation including individual test charts for each tube. This packaging is pretty much the same as the one used for the 1990s Westrex Western Electric production tubes.

The tubes are shown boxed in **Photo 1** and unboxed in **Photo 2**. The wooden box may be a bit over the top, but it is still a nice touch, and the overall packing is very well done—I have seen comparable quality only in the packaging of certain Japanese and Czech "boutique" 300Bs, but none reach the Western Electric level of sophistication.

The 2021 Rossville tubes as such looked very well made—visually the quality is at par with my 1999 samples, or Czech "boutique" 300Bs. The tubes have individual serial numbers engraved in the socket, and the production week is indicated as well—the samples I received are marked 2113 (2021—Calendar Week 13). Carefully inspecting the inner structure, it is noticeable that the tubes are assembled by hand—there are subtle differences in the glass stem and some other parts between the tubes. Compared to my 1999 samples, the plate coating differs, and the actual triode structure is placed about 2mm higher



a)

Western Electric
300B Electron Tube

	Serial No: 300669	Serial No: 300681
Date Tested	3/9/2021	3/10/2021
Test Conditions		
Filament Voltage (Ef)	5 V	5 V
Plate Voltage (Eb)	300 V	300 V
Grid Voltage (Ec)	-58 V	-58 V
Test Results		
Direct Interelectrode Capacitances		
Grid to plate	14.7 pF	14.9 pF
Grid to filament	8.4 pF	8.3 pF
Plate to filament	4.1 pF	4.0 pF
Characteristics		
Filament Current (If)	1.27 A	1.26 A
Plate Current (Ib)	61.9 mA	64.5 mA
Grid Current (Ic)	0.10 uA	0.12 uA
Plate Resistance (Rp)	741 ohms	718 ohms
Grid-Plate Transconductance (Gm)	5117 umho	5281 umho
Amplification Factor (Mu)	3.79	3.79
Delta Gm @ Ef=4.5V	0.4 %	0.2 %

Plate Curves for Serial No: 300669 / 300681
Plate Current (mA) vs Plate Voltage
Ec= 0V to -80V step -10V
© 2021 Western Electric

b)

Western Electric
300B Electron Tube

	Serial No: 216965	Serial No: 216970
Date Tested	4/4/01	4/4/01
Test Conditions		
Filament Voltage (Ef)	5 V	5 V
Plate Voltage (Eb)	300 V	300 V
Grid Voltage (Ec)	-58 V	-58 V
Test Results		
Direct Interelectrode Capacitances		
Grid to plate	14.9 pF	14.6 pF
Grid to filament	8.6 pF	8.4 pF
Plate to filament	4.3 pF	4.1 pF
Characteristics		
Filament Current (If)	1.23 A	1.24 A
Plate Current (Ib)	60.2 mA	62.0 mA
Grid Current (Ic)	0.04 uA	0.05 uA
Plate Resistance (Rp)	690 ohms	675 ohms
Grid-Plate Transconductance (Gm)	5623 umho	5810 umho
Amplification Factor (Mu)	3.88	3.92
Delta Gm @ Ef=4.5V	1.2 %	1.8 %

Plate Curves for Serial No: 216965 / 216970
Plate Current (mA) vs Plate Voltage
Ec= 0V to -80V step -10V
© 1996 Westrex Corporation

Photo 3: Individual test charts come delivered with the WE 300B tubes. Shown here are 2021 Rossville (a) and 1999 Kansas City (b) production charts.

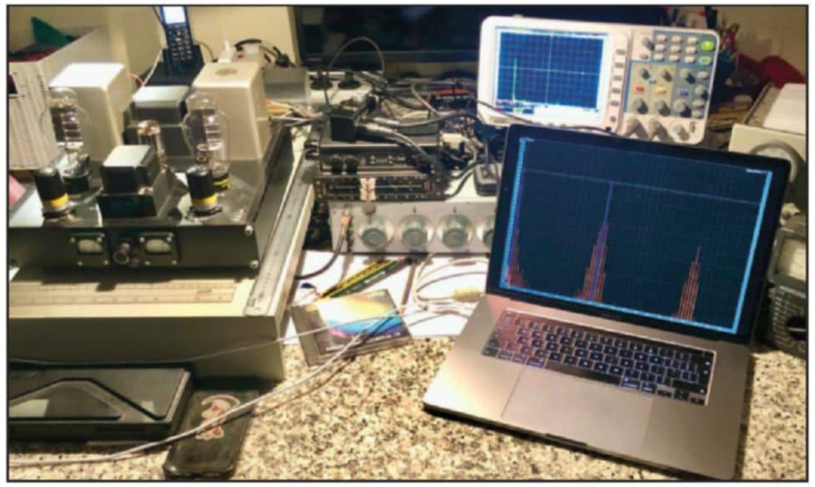


Photo 4: For 300B distortion characterization, I used a homemade power amplifier with a stepped attenuator at input (2dB steps to -40dBr), low distortion hybrid driver stage, stabilized operating point output stage for 300B, low distortion James Audio output transformers reflecting a 3.5kΩ resistive load into the 300B under test.

in the ST bulbs. The structure itself is very similar, including the springs tensioning the filaments, and is aligned perfectly straight.

The individual test charts delivered with the WE 300B tubes (**Photo 3**) show tubes within datasheet specification (median values in datasheet of 300B [4]—by experience, one sigma deviation of primary parameters is better than ±1/6th). As visible in Photo 3, my 1999 reference pair (measured and delivered in 2001) had a slightly lower Rp in the factory test operating point (due to higher gm). WE factory matching for both old and new production was done to mu and Rp. It is of note that the test rig used in factory in 2021 has a better resolution than the one used in the factory in 2001. Furthermore, the curves point to a subtle difference in the grid structure of the 2021 production 300B compared to my 1999 samples—the current cut-off at very high plate voltages is less sharp than in the 1999 samples. This is, however, not a problem in real use—I have seen similar behavior with my old stock (1970s) WE 300B, without detriment in sound or measured distortion performance.

A quick plausibility check for the curves was done by calculating the perveance of the tubes at low grid and plate voltages, and then extrapolating the plate current at some higher values, using the Child-Langmuir space charge equation and the appropriate dynamic mu figures from the datasheets [4], [5]. The calculated values were close to the values indicated in the curves, thus confirming the validity of the curves. With this, I considered the visual inspection passed successfully.

Testing

The visual inspections were followed by a check of the basic parameters on my electron tube test rig (described in the annex) in the test point given in the tube test charts. After 30 minutes warm-up, the basic parameters as indicated in the test charts, including the filament current at 5V, were reached within the test rigs tolerances. It is of note that the curves indicated both 2021 samples being at the bottom end of the allowable tolerance field of the datasheet. For evaluating the perveance, a pulsed emission current test cycle was done at 200V (grid negative at -100V, pulsed to 0V at 100 Hz and 10% duty cycle)—the pulsed current of the tubes reached 310mA (1st) and 320mA (2nd)—median in the datasheet is 340mA.

After that, the new tubes were given a hard stability test—running them for about 100 hours at 36W plate dissipation (operating point 360V/100mA with grid servo regulator), which they passed without problems. Then, static parameters were measured again—notably, dynamic mu remained unchanged within the tolerances of the test rig, but the perveance had slightly gone up, requiring slightly higher negative grid voltages to keep the plate current at 60mA—g_m had increased by a few percent, and the grid current had gone down noticeably. This presumably is because the getters had caught more gas ions in the bulb, activated through the dissipated heat.

I then made a first set of distortion measurements after warming up the tubes in the measurement amplifier for 30 minutes. The distortion measurement system is described in the sidebar at the end of the article and shown in **Photo 4**. Overall, the tubes reached the datasheet specification for the operating point of the test amplifier (WE 300A datasheet, page 5—recommended operating conditions—at 350V/60mA/7W, 1dB below clipping: h2 below minus 30dBr, h3 below minus 44dBr referred to the fundamental), but with relatively high levels of high-order harmonics—tailing off fast, but with significant levels up to h9—see **Figure 1**, column 2, position 1.

The tubes were then inserted into the amplifier used for the listening tests and used for about 400 hours. Thereafter the basic parameters were measured again in the test rig. By that time, the perveance had gone up further, again requiring alignment of the grid bias voltages—total change required now about 5% to keep the plate current at 60mA. The mutual conductance g_m had increased by about 5%, dynamic mu remained unchanged, and the ionic grid current had gone down on both tubes below 70 nA. In the pulsed emission test, the pulsed current now reached at least 340mA on both tubes, thus bringing their perveance to a good average value—the cathodes being activated to full performance in the about 500 hours total operating time.

Distortion measurements were repeated, and showed a notable reduction in higher-order harmonics, all components above h5 disappearing

Figure 1: Harmonic distortion measuremens for the tubes that were tested under varying conditions.

in the noise floor, closing in to the distribution shown in Figure 1, column 2, position 2.

After that, the tubes were reinserted into the main amplifier and used for listening for about another 2000 hours before being measured again in December 2021, bringing the total operating hours to about 2500.

The basic parameters—mutual conductance, dynamic mu, operating point, perveance, within the tolerances of the test rig—remained essentially unchanged to the measurements at 500 hours. The filament current remained unchanged at 5V filament voltage. The residual grid current had further gone down to about 65nA, pointing to a very good vacuum and little contamination of the glass surfaces with evaporated cathode material.

These measurement results are very good so I concluded that the tubes still have a long service life ahead. The advertised long-life expectation seems more realistic after these measurements.

For comparison, I had some less promising experience with low-price Chinese and Russian 300B clones, with many not even reaching 2000 hours before end of useful service life (emission dropped, mutual conductance down more than 30% compared to new tube), and with others, "boutique" 300Bs included, rather alarming total failures due to filament breakage, failure of the filament tensioning springs or thermal runaway due to cathode material deposited on the glass surfaces, forming low resistance connections between anode and grid, pulling the tubes into "latch up"-like conditions.

At this point, concluding that burn-in had been successfully finished, more distortion measurements were performed. The results are shown in Figure 1, column 1, showing harmonic spectra at 1W, 100mW, 10mW and 1mW. It is noticeable that even at 1W, higher-order harmonics tail off fast, and will most likely be masked by the distortion of speaker and ears of the listener, if a sufficiently sensitive loudspeaker is used. I recommend a minimum of 95db (1m, 1W), and the distortion tails off quickly at reduced power.

For comparison, distortion spectra of various 300Bs 1dB below clipping point are given in Figure 1, column 2, position 1–4 and column 3, position 1–3.

The spectral distribution varies significantly between different 300B "incarnations"—the fast tail-off of higher-order harmonics is achieved in a properly burned-in Western Electric 300B. Note the similarity between the 2021 Rossville production and the 1999 Kansas City production examples, and the comparable tail-off in the Czech "boutique" 300B. For comparison, the sample Chinese 300Bs showed quite a different distribution of the higher-order harmonics. The differences in sound are not insignificant. Of note is the spectrum shown in Figure 1, column 3, position 3—the tube has reached end of life (it clips significantly earlier than the other samples, input signal was reduced accordingly). More higher-order harmonics are visible, as the dynamic mu is no longer near constant.

However, the fast harmonic distortion tail-off can only be achieved if the output transformer used has inherently low distortion, the connected load or speaker has a flat impedance characteristic (I recommend speaker impedance correction/linearization networks in the crossovers, even for broadband speakers), and if the driver stage does not deliver high level of harmonics in itself, masking the actual behavior of the output valve.

In Figure 1, column 3, position 4, the behavior of the driver of the test amplifier is shown. It actually produces hardly any relevant harmonics, with all harmonics being at least 80dB below the fundamental, thus not adding significant high-order harmonics to the output signal spectrum.

The quick tail-off of higher-order harmonics is important for the correct processing of (complex) music signals, as music signals contain many frequencies at once, leading to intermodulation

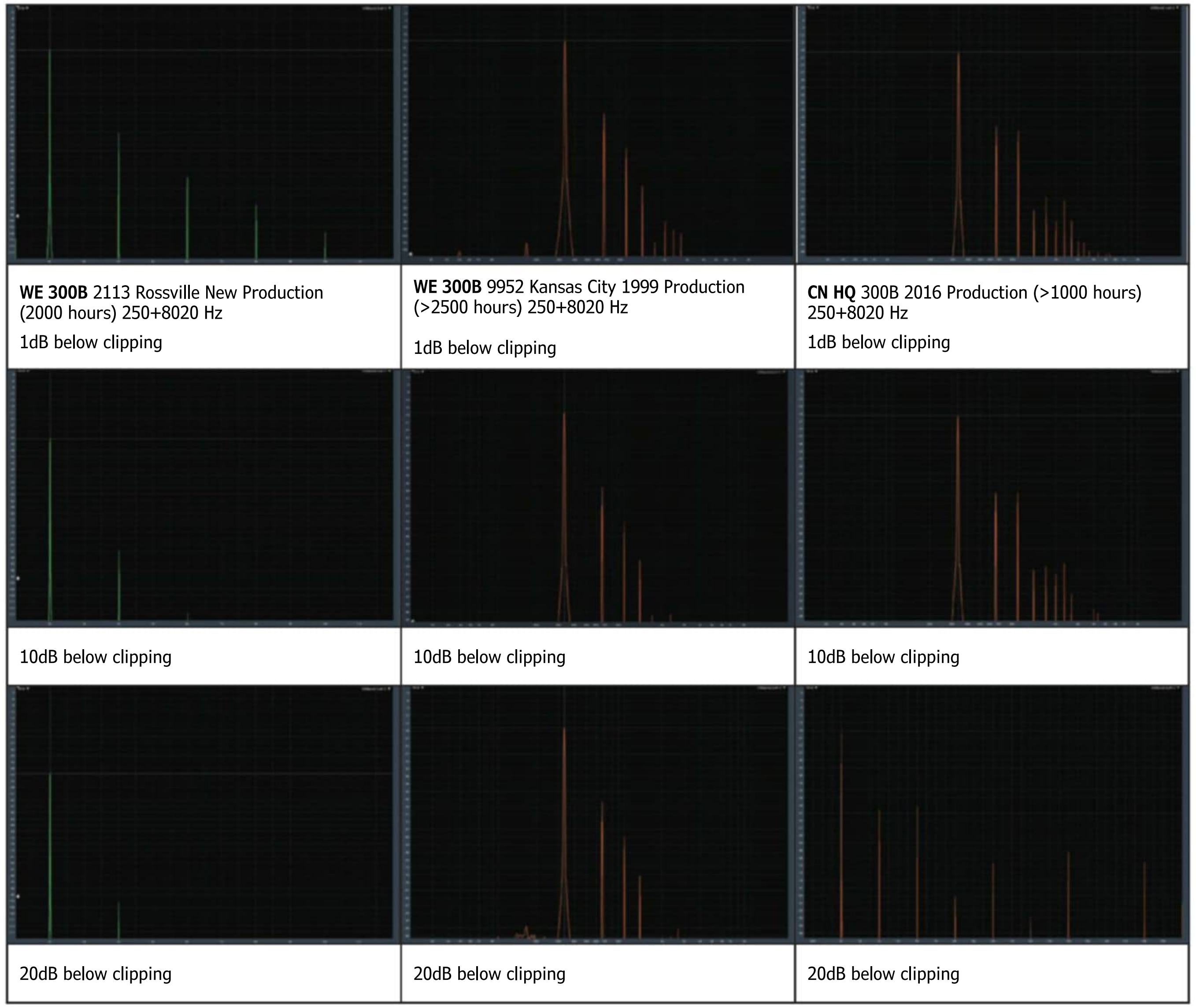


Figure 2: Intermodulation distortion measurements (IMD 250+8020Hz) for the tubes that I tested under varying conditions.

distortion (IMD), read: the mixing of signals by the nonlinearities of the amplifier. Intermodulation of higher-order harmonics bears no harmonic relationship to the actual tones in the music, thus making them disturbing to the listener. For demonstrating the good behavior of the reviewed 2021 Rossville production WE 300Bs, even a bit better than the measured 1999 Kansas City WE 300Bs, please refer to the IMD spectra in **Figure 2**, column 1 and column 2. For comparison, the IMD spectrum of a high-quality Chinese 300B is presented in Figure 2, column 3. The tail-off of sideband spectra is much faster than the tail-off shown by the high quality Chinese 300B—promising a "cleaner" behavior with complex music.

Listening Tests

For the listening tests, I have used my "living room" system, described below in the annex. I regularly listen either with the EL34PP or the 300B single-ended amps driving the Tannoy monitors, alternatively with the 6S33S-V Circlotron OTLs driving the Sonus Faber Guarneri monitors, depending on music type and playback levels. The EL34PP and the 6S33S-V OTL amps were used for "sanity tests" connected to my preamp individually via Eckmiller MR90-St-D faders for adjusting the SPL at the listening position. Adjustment was done with one-third octave noise 800Hz to 1250Hz from the Denon Audio Technical CD (Denon 38C39-7147) and a Brüel & Kjær (B&K) integrating SPL meter at 84dB SPL, to better than 0.5dB, and repeated for each 300B pair used in the setup, as there are noticeable individual gain differences between various 300B types—not so much between WE 1999 Kansas City and WE 2021 Rossville production samples—between those, no realignment was required.

Note: 84dB SPL at -9 dBFs (i. e., leaving 9dB headroom as per EBU specification) is fairly demanding on the amplifier—with my listening distance of 3.5m from the speakers and the speaker's sensitivity of 95dB(1m) at 1W, the amplifier reaches the onset of clipping at 0dBFS, which is technically optimal, but emphasizes that with a standard 300B amplifier, high sensitivity speakers are required. Real listening is on most occasions taking place at significant lower SPL values.

Of note is the history and layout of the 300B amplifier for the listening tests.

In 2017, I built a single-ended 300B amplifier to be used first for a system at the European Triode Festival and then to become part of my "living room" setup. To build it, I used high-grade components I had collected over the years, including Tamura F-7002 Permalloy core output transformers, Lundahl small signal transformers, Unitran and Stoet power transformer and chokes, Welwyn, Beyschlag, Bourns, Dale, and Allen-Bradley resistors, Westermann, Roederstein, Siemens, Jensen, Black Gate, and NCC capacitors, and other selected (new) old stock active and mechanical components. The circuit implements all the experiences I had gained over two decades of building DHT amplifiers in various topologies, and, to use an old adage, was designed to be "as simple as possible, as complex as necessary."

As it is a further development of my measurement amplifier, streamlining the circuit, I named it "MB300+ Generation 2." The amplifier uses a low distortion pentode driver stage built around the C3o (German Post Office line driver pentode) with local NFB, Lundahl input transformers to isolate the inputs and prevent ground loops, a hard LC/shunt regulated power supply for B+, heavy decoupling for other

Photo 5: This is my MB300+G2 Amplifier, which I used for the listening tests.

supply voltages and regulated DC power supplies for the 300B filaments. All stages are run in Class A1. The driver is optimized to low distortion up to the clipping point of the 300B power stage (onset of grid current), keeping THD and IMD of the driver stage very low up to that point—at 50 Veff driver output into 100 kΩ||100pF, all harmonics are below -80dB relative to the fundamental, h3 being the dominant one, higher-order harmonics quickly tailing off. Driver stage IMD is very low as well. As the 300B power stage is not meant to be driven into the grid current regime (Class A2), coupling from the driver to the 300B is capacitive, defining the clipping point by the onset of grid current of the 300B. Due to the high level of filtering and low overall gain, the noise floor is very low. The amplifier is shown in **Photo 5**.

As a consequence of the low driver stage distortion and IMD, its sonic signature is inherently different from many common 300B amplifiers. It is cleaner, less colored, less warm, and less euphonic than most 300B amplifiers with cascaded triode/SRPP/Loftin-White drivers, but also less forgiving to "sub-standard" 300B tubes, as the sound is dominated by the behavior and distortion spectra of the 300B power stage rather than by the high level of harmonics and intermodulation from typical drivers. In that aspect, behavior is comparable to the amplifier used for the measurements.

Because of that, during listening, "the signature," read IMD distortion and grid current behavior of the 300B used in the power stage, becomes rather easily discernible. I normally operate it with Czech "boutique" 300B clones, and put in my old stock WE 300B on occasion, for listening pleasure.

Photo 6: Here is the system that I used for review at home.

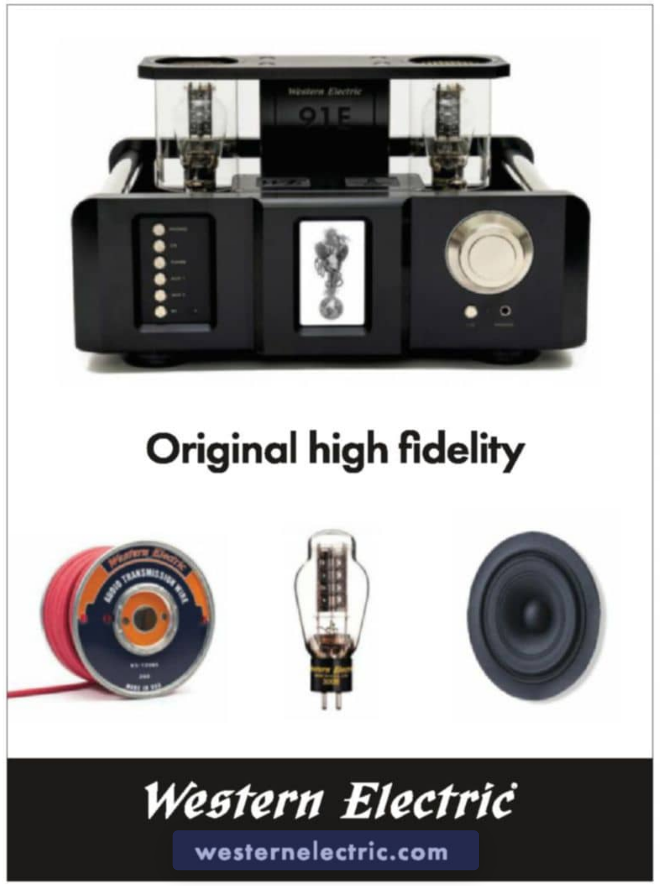


Photo 7: This is the system that I used at the French audio event (November 2021) in order to obtain more subjective opinions regarding the WE 300B tubes.

A suitably long burn-in time for the 2021 Rossville WE 300Bs (and other 300Bs that use the dual carbonate cathode chemistry as described in Peter van Willenswaard's article) is necessary, not only for improving measurement results, but as well for achieving the best possible sound quality. Critical listening let me experience this (requiring A/B swapping of warmed-up tubes, which is not recommended for normal use, as there is always a risk of broken filaments and of burns to the person changing the tubes).

For the first few hundred hours, the WEs sounded a bit lackluster, forward and less resolved than my reference samples that had been used for a long time. Over time they slowly opened up, reaching a good level of performance, which they have held ever since.

The 2021 samples have at last reached a behavior very close to my reference samples (1999 Kansas City and old stock 1970s Kansas City WE 300B). They do not sound exactly equal, but share overall behavior very closely—they are family though, birds of a feather. The differences are subtle, and caused by normal production tolerances—see the IMD measurement in Figure 2 and the curves in Photo 3)—for most uses, I deem them not significant.

For the review I listened to various types of music on the system shown in **Photo 6**, from complex classical recordings to modern lounge jazz, natural voice, acoustic and electronically amplified/enhanced instruments, and electronic music, with good recordings but as well some with errors audible in good reproduction systems. I think that using such "imperfect" music samples, and confirming the discernibility of said errors is an important benchmark for reviewing sound reproduction performance of reproduction systems and components therein, including electron tubes. I note that no reproduction system I ever listened to did fully accurately reproduce live sound of acoustic instruments. The best systems produce a plausible representation or, as I like to call it, an acceptable sonic illusion, and this is what I am looking for in listening.

Overall Impressions

The overall impression in my system was that with the 2021 Rossville WE 300B, the music was represented correctly, producing a suitable illusion and immersive experience—much in line with what was achieved with old production WE 300B and the Czech "boutique" 300Bs that I regularly use. The WEs showed a more forward, engaging representation of the music's mid-range, while the Czech 300Bs seemed more wide-band, showing more emphasis and details in the frequency extremes (Note: the dynamic internal resistance of the Czech tubes was lower than those of the WEs, thus changing the interaction with output transformer and loudspeaker, which is bound to change the sound).

Both the WEs of old and new production and the Czech "boutique" 300Bs presented the music as recorded, not adding information, and not glossing over recording or musician's errors. Compared to some other, "lesser" 300Bs clones, the representation of the music was more transparent, allowing to listen "through" complex passages in the music, without becoming overly analytical. Entry-level 300Bs clones sounded sometimes more euphonic with small, not too complex settings, but quickly became muddy in complex parts (most likely owing to the higher level of IMD).

Thus prejudiced positively by my own listening, I put the tubes to another "hard" listening test by

About the Author

Michael Boele is a German-born Telecommunications and Electronics Engineer (Dipl.-Ing. TH (Nachrichtentechnik), MSEE) who has been working on ground and ground-to-space communications and navigation. He acquired his MSc degree in the 1980s, and worked on measurement and control systems for high voltage electrical power distribution systems and on RF/communications measurement systems. In his professional life, he moved away from electronic hardware design, and—to keep his dexterity in this field—he took up collecting tubes and designing audio amplifiers and test equipment. Over the last 25 years, he has designed many small signal and power amplifiers, push-pull and single ended, tube-based, and hybrid, and is considered by some as a living database on electron tubes and their uses. He built his first 300B SET amplifier after reading Jean Hiraga's *Initiation aux amplis à tubes* in 1999, first intrigued, not expecting much, but being positively surprised. He has been building more of them over the years, using measurements and listening experience for their optimization, acquiring many "incarnations" of Western Electric 300B tubes and clones, some Western Electric old stock originals, some Western Electric re-issues and many third-party 300B clones striving to meet original specification as well as "improved" types.

carrying them, together with amplifiers, speakers, preamp, sources, cables, assorted recordings on CD and CD-ROM and a bunch of different high-grade 300B clones and "improved" types to an audio festival with international participation held in France in November 2021 (as my review covers a new commercial product, the organizers asked not to mention the name of said event). The goal was to have a larger audience of experienced and critical listeners partake, to corroborate or contradict my impressions. I brought along my two remaining 300B Amplifiers—the MB300+ and the MB300+-Generation 2. The system as used and presented at the festival is shown in **Photo 7**.

The resulting comments were in line with what I had found myself. The new production WE 300B were in general perceived as WE "family members" and the majority positively commented upon them—from "if you had not disclosed them as new production, I would have considered them as good old stock samples" to "subtly different, but clearly from the family"and one outlier "the difference to the 1999 samples is not subtle, but much less than to third-party clones." The common denominator was that the tonality and the voicing of the system with the new production WE 300B was very rich and engaging, but precise at the same time—producing a worthy sonic illusion.

The system held up over various levels of loudness, while some other 300B clones did not sound "right" at some levels, either being unengaging at low levels, with the loudness threshold required to be passed to create an acceptable level of illusion, or falling apart and sounding unpleasant at higher level. In general, the "WE 300-B sound" for both 2021 and 1999 WE production samples was favored, followed by the sound of the Czech "boutique" 300Bs.

Conclusion

I enjoyed reviewing the Western Electric 2021 Rossville production WE 300B tubes, both the measurement and the listening parts. I pushed the tubes through their paces, hard, and did not find the experience wanting.

The new production WE 300B samples reviewed are good, even very good. After burn-in, they have been very close to my 1999 WE 300B "reference" samples still produced in the Kansas City factory, enough so to be called birds of a feather. There are subtle differences driven by the deviations in characteristic curves, read mutual conductance, gain factor, and internal resistance. It is noted that these deviations are well within the expected production tolerances as per old production datasheet specifications.

From the beginning, measurement of characteristic parameters (operating points, gm, mu, leakage currents, perveance, and perveance drop when filament voltage is reduced) were in line with the individual acceptance test charts delivered with the valves. In line with lore and expectations, they took more than 300 hours of burn-in to stabilize sonically. In measurement, perveance and gm increased to datasheet average values over that time, and the grid leakage current went down by almost 50%, pointing to the already good vacuum improving—THD and IMD characteristics improved a bit as a consequence—in my opinion that accounts for the improvement of the sound over this burn-in period.

After that, the review samples have kept up very well during the more than 2500 hours they have been used for thus far, with no visible ageing after burn-in. The perveance and mutual conductance have remained unchanged, within the tolerances of my measurement setup, and the isolation resistances and vacuum have held up as well—so it is fair to expect the tubes to last very long, making the five years manufacturer's warranty a realistic provision.

As for the "sound" provided in my setup, the tubes clearly belong to the Western Electric family. Again, there are subtle differences to the WE old stock and to the 1999 WE Kansas City production samples, but they are at level that manifests themselves only by direct comparison (A/B swap of burned in and warmed up tubes).

If the production line and process remain stable, and average new production tubes have similar properties to the ones reviewed, potential buyers will receive a quality product that lives up to its name, backed by a meaningful long-term warranty. Thus, the risk taken seems low when compared to the purchase of NOS WE 300B tubes on the market or the purchase of high-priced third-party "high-grade" clones. I also noted that the 2021 WE 300Bs—in my system as described in this article—did sound good with all the music samples from a wide range of genres, and over a wide range of volumes on mid-high efficiency loudspeakers.

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[3] J. Hiraga, *Initiation aux amplis à tubes*, (ISBN 978-2100041169)

[4] Western Electric, WE 300B Datasheet, https://frank.pocnet.net/sheets/084/3/300B.pdf

[5] Western Electric, WE 300A Datasheet, https://frank.pocnet.net/sheets/136/3/300A.pdf

Equipment Setup Used for Review and Measurement

The "Home System" shown in Photo 5 and Photo 6 includes:

Analog Sources:

- EMT938 direct drive broadcast turntable with EMT-929 pickup arm, Denon DL-103R and modified EMT RIAA preamp (Pikatron step-up transformers and Lundahl LC-equalization),
- Denon DP-62L direct drive turntable with Denon DL-103 or DL-301, Lundahl step-up transformers and Creek OBH-15 RIAA preamp (modified circuit),
- Telefunken EBU3156 Broadcast relay receiver with R&S MPX Stereo Decoder module, quartz-tuned to NPO Radio 4 (NL)

Digital Media Sources:

- DAC: Benchmark DAC1 fed from TC Electronic Digital Connect X32 via AES-3
- CD: Mark Levinson No. 39S (analog output into preamp, AES-3 output into DAC1)
- High-resolution digital file playback: Apple Mac Mini Core i7 (2x1TB SSD), connected via Firewire hub into Apogee Duet feeding preamplifier, inputs on preamp tape out.
- Wireless streams: Wi-Fi and Bluetooth receiver feeding DAC1 through TDIF.
- SACD: HHB UDP-89, analog output feed into preamp, SPDIF output into DAC1

Preamplifier:

- Mark Levinson No. 380S with Danner HpHCF-4k/85 ear passive curve correction equalizer for low volume listening, looped through preamp tape loop
- Eckmiller MR90-St-D-600/200-K symmetrical passive faders (200Ω output impedance) as passive volume control for level trimming

Power Amplifiers:

- MB300+G2: Home-made 300B SE Amplifier with C3o low distortion driver with local NFG, Lundahl small signal and Tamura Permalloy output transformers, no overall NFB—used for the new production WE300B listening tests (see Figure 7).
- For comparison, Graaf GM-20 OTL (6S33S-V PPP/circlotron output stages, augmented with speaker protection crowbar circuits) and Hovland Sapphire (EL34 hybrid PP, modified gain stages, power stage, power supplies) were used.

Loudspeakers:

- Tannoy DMT-12 ii (impedance-corrected), sensitivity 95db (1W/1m)
- "Sanity Check" speakers: Sonus Faber Guarneri Hommage (impedance-corrected), driven by BAT VK-55 PPP or Graaf GM-20 OTL, augmented with Neumann KH-810A subwoofer combined with DSP Anti-Mode bass management system

Cabling, Connectors, Meters, Power Supply:

- Power cords, small signal, measurement—balanced and unbalanced—Amphenol, Belden, Cordial, Eupen, Sommer, Suhner
- Passive loudspeaker cables: vdHul The Clearwater on DMT-12ii, 10 AWG Silver/PTFE home-configured speaker cables on Guarneri Hommage
- Connectors: Amphenol, Hirschmann, Neutrik, WBT, Furutech
- Level Meters: RTW 1113 analog (balanced), NTP277-401 digital/AES3, Bruel&Kjaer 2235 SPL meter with capsule 4165, filter 1625, calibrator 4230
- Ground loop isolators/distribution units: Lundahl, Pikatron, Samson
- Mains Supply: Samson mains conditioner/surge protection unit, Suhner mains filters, Brennenstuhl, Knuerr power distribution strips, Eupen and Sommer cables

Test Equipment:

- For 300B distortion characterization, I used a homemade power amplifier with a stepped attenuator at input (2dB steps to -40dBr), low distortion hybrid driver stage, stabilized operating point output stage for 300B, low distortion James Audio output transformers reflecting a 3.5 kΩ resistive load into the 300B under test and 8Ω dummy load made from Vishay induction-free power resistors. This amplifier is the "MB300+" mentioned in the introduction.
- Distortion measurements were done with a "homebrew" setup using Rational Acoustic SMAART V7 software on OSX, and USB/Firewire-connected measurement ADC/DAC setup (24-bit, >19 bits usable dynamic range, generator output +24dBU at 0dBFS, better than 80dB harmonic suppression), assorted Anritsu and Eckmiller attenuators, for calibration Rohde&Schwarz SUN2 and UPA, Wandel&Goltermann TFSK-40, TFEK-41, Fluke 8920A, Siemens and HP stepped attenuators were used. Accuracy is better than 1dB down to -90dBr.
- For 300B static characteristic measurements, a homemade test setup was used. I built it using Heinzinger, Delta Elektronika, Statron, HP, and Meanwell (filament) power supplies, Fluke, Keithley and APPA (TRMS) multimeters, Dale precision measurement resistors, Johnson UX4 socket, homemade sine and pulse generators and Owon digital oscilloscopes (8 bit and 14 bit). Calibration was done with Tettex (CH) calibration resistors/capacitors and a Fluke calibrator was used. Accuracy is better than 0.5% for DC static parameters and better than 2% for AC parameters.

The System used at the French Audio Event (November 2021) shown in Photo 7 includes:

- CD and Broadcast Wave file player: Fostex CR-500—balanced output 5.5 Veff @ 0dBFS
- SACD: TEAC CD-1000 modified with balanced Nuvistor output stage
- Preamplifier: Krell KSL-2 with phono board and modified output stage
- Power amplifiers as described in measurement and auditioning systems
- Loudspeaker: Tannoy DMT-12 ii (impedance-linearized)
- Cabling: Speaker cable vdH The Clearwater with Hirschmann plugs, Interconnects balanced Belden/Cordial with Neutrik (XLR), Interconnects unbalanced Suhner PTFE dielectric dual shield coax/Furutech (RCA connectors) connectors
- Power distribution/mains filter/OVP: Knuerr power strips, Eupen and Sommer cables

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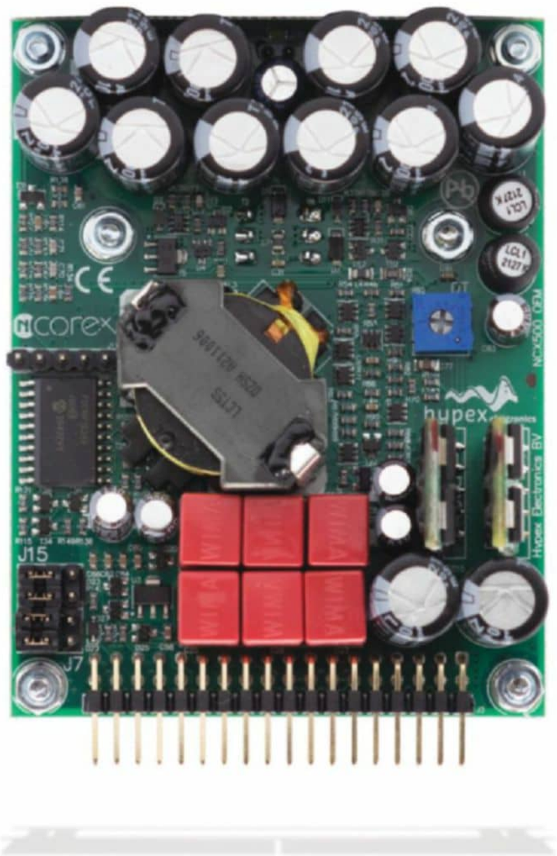

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GLASS AUDIO

Meet the Pentriode

By
Alan Kimmel

This article delves into the concept of connecting commonly available pentode tubes as triodes, creating a circuit that excels in linearity. The author proposes different possible approaches, including for a mu stage.

Shortly after my first tube audio article, "The Mu Stage," was published in 1993 in *Glass Audio* magazine, I developed a simple circuit that I called the Pentriode. I even wrote a tentative article about the Pentriode in 1995, and I considered submitting it around that time but somehow never got around to it. I finally decided now was the time for me to share a blast from my past as I show you the Pentriode, this time with additional information.

The Circuitry

Probably everyone who reads anything about tube audio circuitry knows that a pentode can function as a triode when its screen grid (Grid 2) is connected to the plate—see V1 shown in **Figure 1**. When triode connected, many pentodes can be outstanding very linear triodes.

The Pentriode is formed by making one simple change to Figure 1: Connect V1's screen grid, not to V1's plate, but to the cathode of cathode follower (CF) V2—see **Figure 2**. In Pentriode mode, V1 essentially operates as a triode, but its screen grid current no longer burdens the plate of V1. Instead, CF V2 provides all current to V1's screen grid. Pentriode mode brings nice advantages.

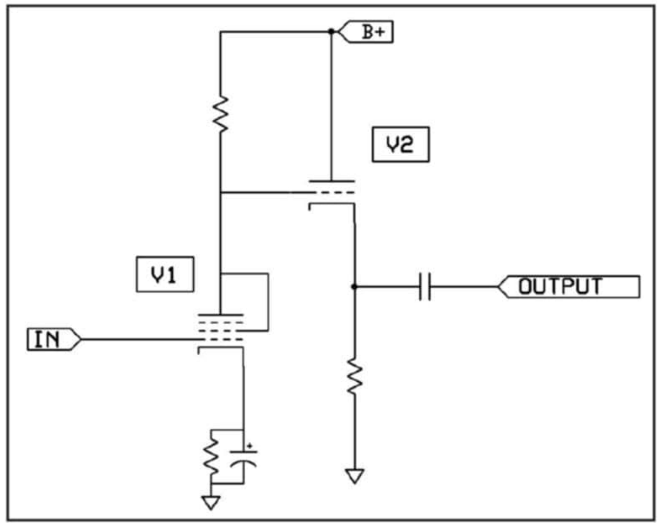


Figure 1: This is a triode-strapped pentode connected to a cathode follower buffer.

Pentriode mode is not strictly triode mode nor is it pentode mode. It is also not "ultra-linear" (aka partial-triode) operation. I had to come up with an entirely new name for this circuit, and the name Pentriode seemed appropriate. Pentriode mode is definitely most like a triode mode, with the same (or closely the same) mu and gain as the pentode would have in conventional triode connection. In fact, designing a Pentriode stage is as simple as designing a standard triode stage, the only extra part being the addition of a simple cathode follower.

Cathode follower V2 can be any active device, including a triode CF or a pentode CF (my favorite follower for audio—see **Figure 3**). There are also several other options: You could make a hybrid Pentriode by using a field-effect transistor (FET) source follower in place of V2, or a bipolar junction transistor (BJT) emitter follower, or a Darlington emitter follower, or an insulated gate bipolar transistor (IGBT) emitter follower, or a Sziklai pair follower, or an IC voltage follower, or a current follower, and I'm sure several other follower types. V2 could also be a follower consisting of a vacuum-state device, solid-state device, gas-state device, or any state device.

By the way, it is my standard practice to use grid stopper resistors for every control grid and every screen grid. Suppressor grids don't need a stopper resistor. In audio applications, I normally use a value of 220Ω for grid stopper resistors.

Pentriode's Benefits

It is important to note that some pentodes really excel in Pentriode mode, more so than other pentodes. Some pentodes give even less distortion in Pentriode mode than when the pentode is connected in standard triode connection. It would be nice if we could tabulate a list of the pentodes that excel at Pentriode operation.

It is also possible to make a Pentriode mu stage, which is probably my favorite type of mu stage. It has all the advantages of mu stage operation including wide bandwidth (BW), low distortion, low output impedance, plus the advantages of Pentriode operation. A practical example is shown in **Figure 4**. With regard to Figure 4: 1) The purpose of the 27kΩ resistor is to drop a few DC volts so that V1's screen grid voltage is the same as V1's plate voltage, to closely emulate triode operating conditions for V1. 2) When a 6AC7 tube is used for audio, its heater is best powered by DC. 3) The heater of V1 is pins 2 and 7; the heater of V2 is pins 2 and 7.

GLASS AUDIO

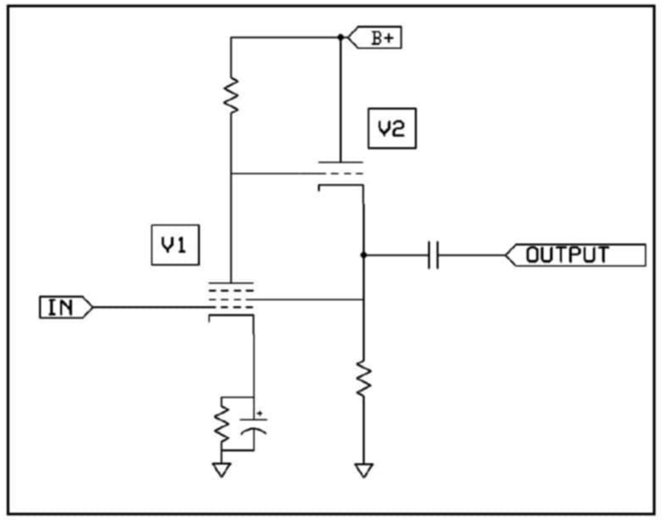


Figure 2: This schematic shows the Basic Pentriode (circa 1995).

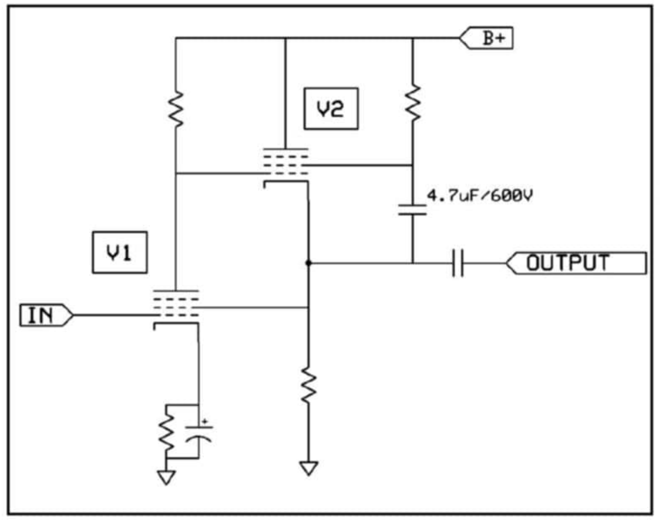


Figure 3: Here is an improved version of the Pentriode.

Here are a few notes for every schematic in this article: 1) The heater supply of V1 should be grounded, but the heater supply of V2 should be floating. 2) The DC voltage at the cathode of V2 should be in the neighborhood of half B+. 3) For clarity of the schematic diagrams, the suppressor grid (G3) of every pentode is shown not connected to anything, but do connect G3 to the pentode's cathode.

Practical Application

I have a friend who is a triode fan, and I modified his stereo single-ended triode (SET) amplifier by converting its voltage gain stage into a mu stage, and he was thrilled with the increased realism and musicality that brought to his amplifier. But I took it a step further and also installed a switch that lets him switch between triode mu stage and Pentriode mu stage operation, but I did not tell him the switch positions—I only told him that the switch gives him two different amplifiers. (Note that such a switch must be switched only when the circuit is OFF and COLD, to avoid sending a large THUMP into the speakers.) I asked my triode fan friend to audition his modified SET amplifier and tell me which switch position sounds best to him. He reported that he prefers the switch position that happens to be the Pentriode mode!

Overall Assessment

In conclusion, listening tests as well as measurements show that Pentriode operation can be superior to either pentode or triode operation. If triode gain is all the gain you need in your application, which is often the case in audio, I believe that the Pentriode may well be the ultimate triode for the reproduction of music!

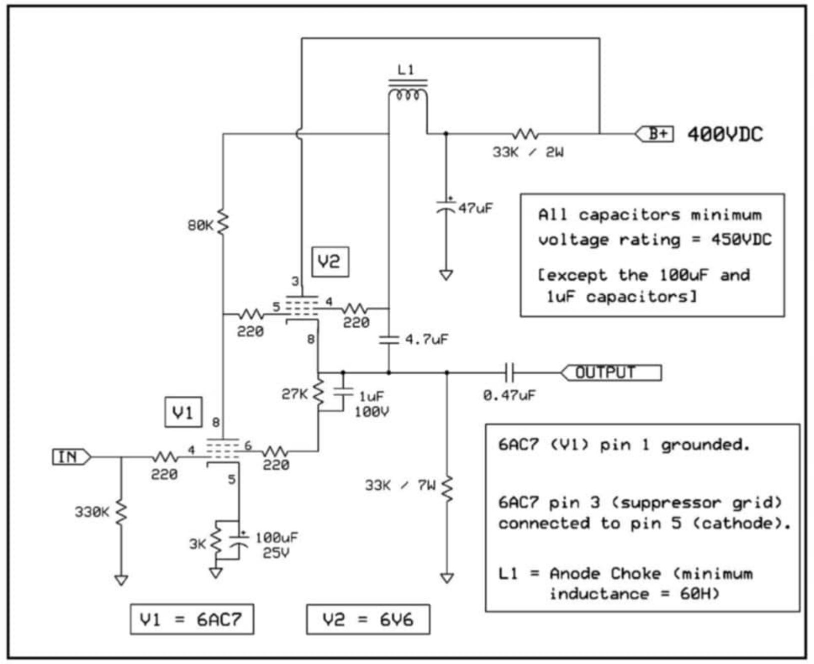


Figure 4: The schematic shown here is a Pentriode mu stage example.

About the Author

Alan Kimmel has been interested in electronics ever since he was introduced to home-brew stereo systems early in life. He enjoys inventing vacuum tube and solid-state audio circuits, as well as non-audio inventions. He has an A.S. degree in Electronics, and an A.A. degree, but is largely self-taught. He can be reached at: airdlab@mail.com

Adding Bluetooth to a Tube Amp

Some might find it heresy, but these days we can buy tube amps with Bluetooth, Wi-Fi, or LAN connectivity installed. In this article, Merlin Blencowe details how to derive +5V from an existing heater circuit without upsetting things and allowing us to connect existing modules with Bluetooth, Wi-Fi, and more.

By
Merlin Blencowe

Photo 1: The author used a no-frills, PCB-type module, which has no buttons—as soon as power is applied it turns on and waits for pairing.

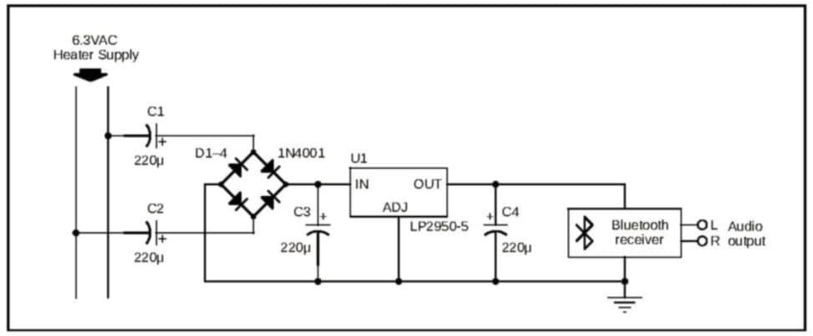


Figure 1: Schematic for the Bluetooth power supply. Be sure to observe polarity.

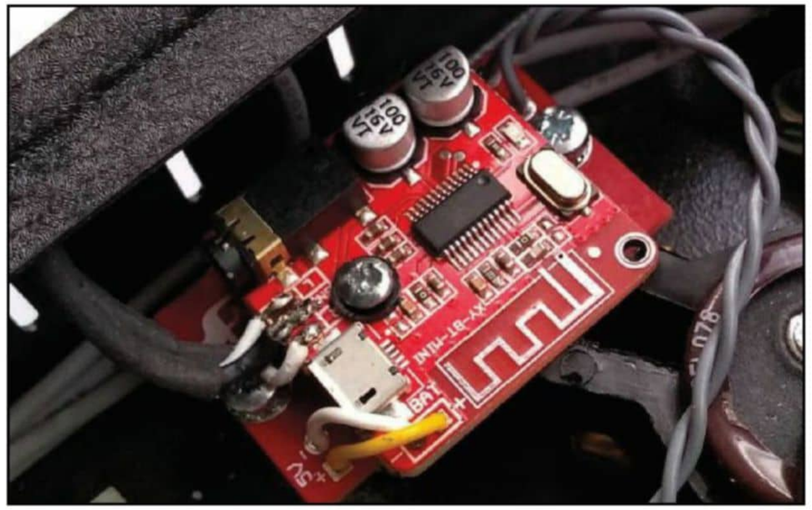


Photo 2: Here, the power supply PCB is piggy-backed onto the Bluetooth module.

These days, adding wireless audio to a gadget is quite easy. There are many inexpensive Bluetooth receiver modules available on the Internet, and recently I have been adding them to my old amplifiers. To do so, I disconnect one of the old auxiliary inputs and route it instead to the output of the Bluetooth module, so the input selector switch on the front of the amp now has Bluetooth as one of its options. I used a no-frills, PCB-type module, which has no buttons—as soon as power is applied it turns on and waits for pairing (**Photo 1**).

Powering the Amp

However, this does raise the problem of where to obtain power from, as a Bluetooth module typically requires 5V DC at around 20mA to 40mA. This is simple enough in a transistor amplifier since relatively low-voltage DC is already available; only a 5V regulator needs to be added. But what about a tube amp? Trying to take an extra 40mA from the B+ supply is out of the question since the power wastage would be extraordinary, not to mention heat dissipation inside the chassis.

Fortunately, a simple solution is possible if the amplifier has an ordinary 6.3V AC heater supply, though it is not quite as simple as adding a bridge rectifier. A bridge rectifier alone would upset the existing heater referencing—typically a grounded center tap or humdinger, though sometimes one heater leg is grounded. Instead, the rectifier must be capacitor-coupled from the AC supply, thereby leaving the original heater grounding arrangement completely unadulterated. Another advantage of this capacitor-isolated supply is that it suppresses the annoying buzz that can otherwise arise when powering a Bluetooth module from a source with a shared ground.

Figure 1 shows the circuit I used (capacitors can be 25V-rated or better). This should produce about 8V DC after rectification, which is then regulated down to clean 5V. An ordinary voltage regulator might work, but to be on the safe side I used a low-dropout regulator, in case of sag under load or varying wall voltage. The LP2950-5 happens to be the cheapest device available to me, and its 100mA limit is more than sufficient, though any other 5V regulator should suffice.

Creating a Small PCB

I created a small PCB for all the power supply components (**Photo 2**), which piggy-backs onto

Accommodating Different Valve Heaters

Valves with unpopular heater voltages are often much less expensive than their 6.3V equivalents, while being otherwise pin compatible. A simple method for allowing two valves with different heater voltages to be used interchangeably is to use a carefully chosen heater supply voltage, plus an equally carefully chosen dropping resistor on each valve socket. With the right combination, two different heater types will receive the correct voltage (assuming one requires more voltage but less current than the other).

To find the right combination, call the heater voltage of the first valve type V_1, and its nominal heater resistance R_1. Likewise for the other valve type call its heater voltage V_2 and heater resistance R_2 (the nominal heater resistance is simply the rated heater voltage divided by the heater current, given on the datasheet). The unknown dropping resistor R_x must then be:

$$R_x = \frac{R_1R_2(V_1-V_2)}{R_1V_2-R_2V_1}$$

And the heater supply voltage must be:

$$V_x = I_1(R_1+R_x)$$

where I_1 is the heater current of the first valve type.

For example, the ECC88/6DJ8 needs 6.3V at 365mA, so its heater resistance is 6.3/0.365 = 17.3Ω. The PCC88/7DJ8 needs 7V at 300mA, so its heater resistance is 7/0.3 = 23.3Ω. Applying these figures to the previous formula:

$$R_x = \frac{17.3\times23.3\times(6.3-7)}{17.3\times7-23.3\times6.3} = 11\Omega$$

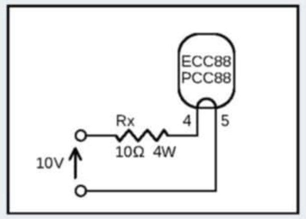


Figure 1: A 4W resistor would be a good fit for this project.

And:

$V_x = 0.365 \times (17.3 + 11) = 10.3V$

But the close standards of 10V and 10Ω work well enough. The power dissipated by R_x can be found from I^2R, where I is the largest heater current. In this case it would amount to $0.365^2 \times 10 = 1.3W$. A 4W resistor would be a good idea, as shown in **Figure 1**.

In a similar vein, some electrically equivalent valves have different pin configurations. For example, the ECC83/12AX7 can be wired up with its heaters in series for a 12.6V supply, while pin-9 (heater center tap) is unused. The 6N2P/6H2П is a Russian equivalent, but its heaters are connected in parallel and require 6.3V, while pin-9 is an internal shield. The two types are therefore not directly interchangeable, which is a shame.

Figure 2 shows a circuit I have used to overcome this incompatibility. When an ECC83 is plugged in, as depicted, the base of the Q_1 is connected to the heater common point, and it will act as an emitter follower. The default 5V regulator voltage will be jacked up by the heater voltage of the "lower" heater, plus V_{be}, plus the drop across D_1, which altogether works out at about 12.6V. Conversely, if a 6N2P is plugged in, pin-9 will be connected to nothing but the internal shield. The base of Q_1 will be pulled down by R_1 so the regulator voltage will only be raised by V_{be} plus the diode drop, making 6.3V. C_2 is necessary to stabilize the regulator for capacitive loads (e.g., C_1), and it bypasses the valve screen too. D_1 and Q_1 can be any general purpose devices as they only pass the few milliamps flowing out of the adjust pin. The regulator will need a small heatsink.

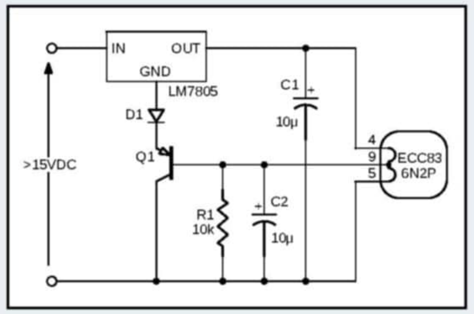


Figure 2: This is a circuit the author has used to overcome the problem when some electrically equivalent valves have different pin configurations.

the Bluetooth modules I used, being careful not to obstruct the antenna with any metallized parts. Depending on how "leaky" your chassis is, you might need to make a hole or gap in it near the antenna, though the AC20BPC7764 modules I chose are surprisingly good at receiving from inside a metal chassis with only ventilation slots, at least over the distance of a room, which is all I really needed. Of course, a wooden chassis, or one with a completely open bottom, should have no reception problems at all.

Conclusion

Since adding Bluetooth to this amplifier I find I actually use it much more, usually to stream from my phone or laptop. The quality may not be exemplary, but it's plenty good enough for YouTube videos and TV shows.

About the Author
Merlin Blencowe is an analog engineer working for AMS Neve, Ltd. in the UK where he specializes in pro recording equipment and studio consoles. He also researches tube technology for guitar and hi-fi use, and has published numerous articles and books on the subject.

Editor's Notes Regarding the Retrofit

The idea of retrofitting an old classic tube amplifier design in order to introduce streaming audio sources, including wireless audio, has many implications, the most important of which should be—Can you simply do it with an external module that can be hidden somewhere, without necessarily doing modifications to a product that is probably left alone as is?

Assuming the answer to that question is: "I don't care, I've done so many modifications already" or "This is my DIY audio amplifier, and I'll do whatever I want with it," —then fine, go ahead with this.

The following question is—What wireless/streaming module should I buy? And our advice to that question is try to future-proof your investment as much as possible.

Meaning, buy the most recent module you can find, supporting the latest Bluetooth specifications possible (nothing below Bluetooth 5), and look for support of the latest services over Wi-Fi, including AirPlay 2.

Most modules in the market not only offer Bluetooth but also Ethernet LAN and Wi-Fi, with direct support for high-quality streaming services, including Spotify Connect and Tidal Connect, which are direct receivers, totally independent from external sources (smartphones or tablets can still be used just for remote control).

Most of these modules require between 5V to 20V DC and you might also look at additional challenges from the different connectors, considering you will probably need to keep those accessible.

When using Wi-Fi or an Ethernet connection directly from the home router, modules should also allow for higher quality audio codecs than those supported on Bluetooth, including uncompressed streaming and high resolution audio support.

Another option is to look for newer modules that also work as a USB interface—and preferably the updated USB specification over Type-C, since it would also offer support for Ethernet or HDMI with a simple cable adapter. Although a module with USB interface is probably a bit more expensive and might complicate the design considerably.

Most online retailers carry a few of those modules but they don't necessarily restock them as frequently as those specifications are being updated. So, beware of older Bluetooth 4.2 modules in the market that don't even support any higher quality streaming audio codecs other than the basic SBC.

Also, with regard to Bluetooth, take care with regard to a robust radio implementation (Class 1) and where to eventually place an external antenna. Consider how even reputed manufacturers, such as McIntosh Laboratories, are updating their designs almost every two years in order to offer the most up-to-date options. For an excellent reference of what adding an audio streaming module entails, look no further than McIntosh's MB20 Class 1 Bluetooth 5 Transceiver ($500), which supports AAC and aptX HD codecs.

For another related perspective, which considers having a tube line-level preamplifier stage to match the relatively low output voltage amplitudes of a turntable and Bluetooth receiver without constantly needing to readjust volumes, we recommend reading Bill Reeves' project article, "Repurposing an Old Preamp for Line-Level Duty."

I have frequently recommended that manufacturers should avoid directly integrating technologies that are evolving fast and that might quickly become obsolete, which doesn't make sense in expensive and well-designed audio electronics equipment, from integrated media services that are not hardware upgradeable, to high-end amplifiers that are best served by using a connection to external sources, such as preamplifiers with integrated DAC stage and streaming.

NAD Electronics or Bang & Olufsen are examples of brands that have repeatedly echoed those same concerns and are offering replaceable modules in all their latest systems, in order to compensate for that. I offer the same recommendation to our DIY readers, even if some of you would probably enjoy the idea of continuously upgrading your systems.

Effect of Air Conditions on Sound Propagation

Our acoustics expert details why atmospheric conditions might affect sound propagation, how this impacts acoustical parameters, and what can be done to adjust for the changes.

By
Richard Honeycutt

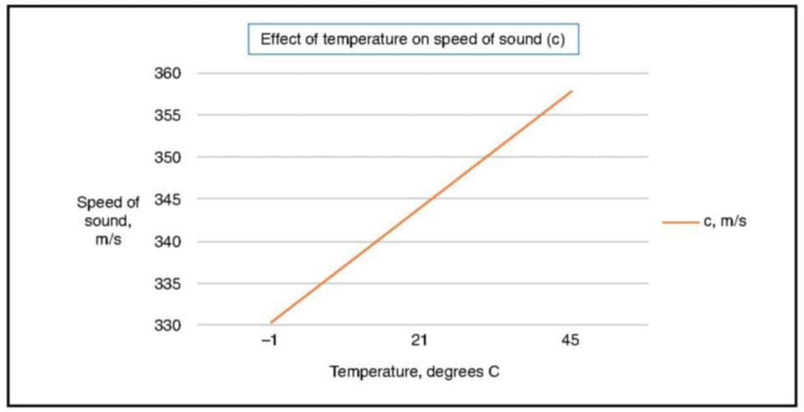


Figure 1: This illustration shows the effects of common range of outdoor temperatures upon the speed of sound.

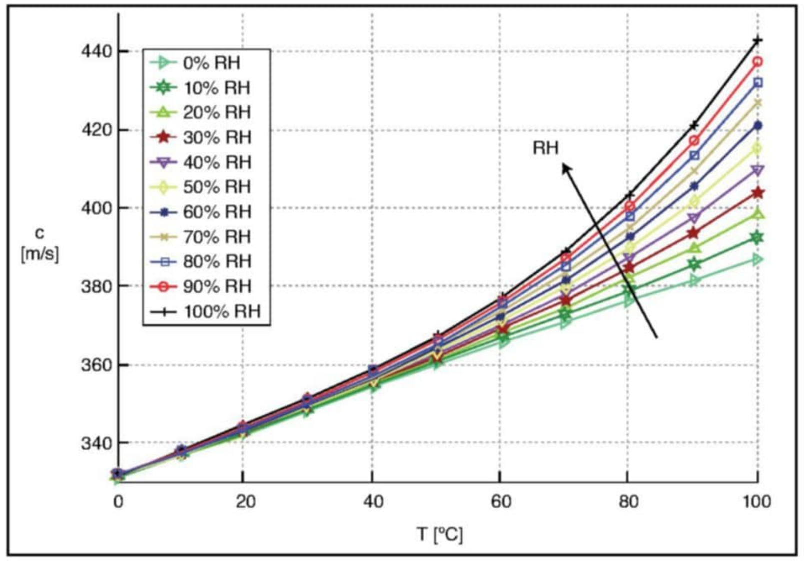


Figure 2: Relative humidity has a small effect upon *c* at room temperature, but the effect increases with temperature. (Source: O. Cramer, "The variation of the specific heat ratio and the speed of sound in air with temperature, pressure, humidity, and CO_2 concentration," *Journal of the Acoustical Society of America*, 1993.)

In a recent discussion with a few colleagues, a question was raised about the possible need to readjust sound system controls and/or DSP settings to compensate for differences in atmospheric conditions (e.g., temperature, relative humidity, and barometric pressure). The discussion then broadened to include other acoustical parameters, such as STI and reverberation time (RT), even though there is no way to compensate for these changes using sound system adjustments.

Factors Affecting the Speed of Sound in Air

It is well known that *c*, the speed of sound in air, depends upon temperature. The speed of sound at 0°C and one atmosphere of pressure (1.013 × 105 Pa) is given by:

$$c_0 = \sqrt{\frac{1.402 P_0}{\rho_0}} = 331.6 ms$$

where P_0 = atmospheric pressure and ρ_0= the density of air at 0°C and one atmosphere of pressure.

The temperature dependence of *c* upon temperature is given by:

$$c = c_0\sqrt{\frac{T_K}{273}}$$

where T_K= temperature in kelvins.

Figure 1 shows the speed of sound in dry air at three common outdoor temperatures, along with a trend line.

Since humid air has proportionately more water molecules than dry air, it makes sense that the speed of sound is affected by humidity. As you can see from **Figure 2**, the effect of humidity depends upon temperature. This is because as temperature increases, the proportion of water molecules to nitrogen, oxygen, and other "dry-air" molecules increases, for a given relative humidity. Thus in non-air-conditioned spaces, the speed of sound is considerably higher on a hot summer day than during the winter.

When barometric pressure is higher, so is the density of air. As shown in the first equation, c_0 is proportional to the square root of pressure. However, barometric pressure at sea level usually varies only between 28.5" and 30.7" of mercury, which corresponds to a range of about 0.074 atmospheres. Based upon the square-root dependence, this would change the value of *c* by less than 13m/s. In fact, if the ideal gas approximation is used for air, *c* does not depend at all upon barometric pressure.

The speed of sound in air depends not only upon wind speed, but also upon the relative direction of the wind and of the sound propagation. When the wind is in the direction of sound propagation, the sound travels faster. Conversely, an opposing wind direction decreases the sound speed. **Figure 3** illustrates this effect, which is mainly of concern in outdoor venues.

When a sound wavefront crosses a boundary between two regions having different values of *c*, the direction of wave propagation will be affected. This effect is called refraction.

Imagine a row of soldiers marching from east to west and encountering a muddy field whose boundary stretches from northeast to southwest. The soldiers at the southern end of the row will be slowed down by the mud, and if the soldiers remain in a straight line, the line's motion will be deflected southward. **Figure 4** illustrates refraction caused by temperature rising with height (positive temperature gradient) or temperature falling with height (negative temperature gradient).

Sound Absorption

For several reasons, some sound is absorbed when a sound wave passes through air. This effect increases with frequency, as illustrated in **Figure 5**. In practical use, the effect of this absorption is quantified as either dB/m (or dB/ft) in analysis of outdoor sound propagation, or a sound absorption coefficient in analyzing indoor venues.

In the latter case, the effective sound absorption coefficient of the air depends upon the cubic volume of the venue. The effects of temperature and humidity upon sound attenuation

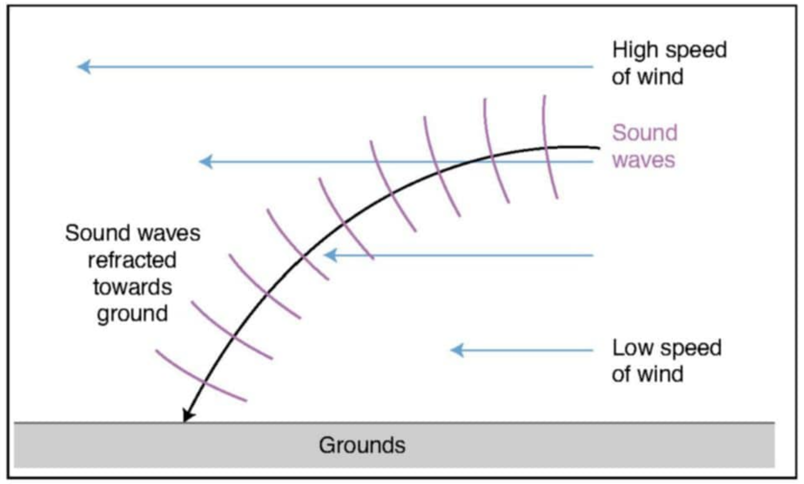


Figure 3: Variation in wind speed with height can cause diffraction. (Source: Physics Stack Exchange "Newtonian mechanics - Can wind bring sounds sooner towards me?")

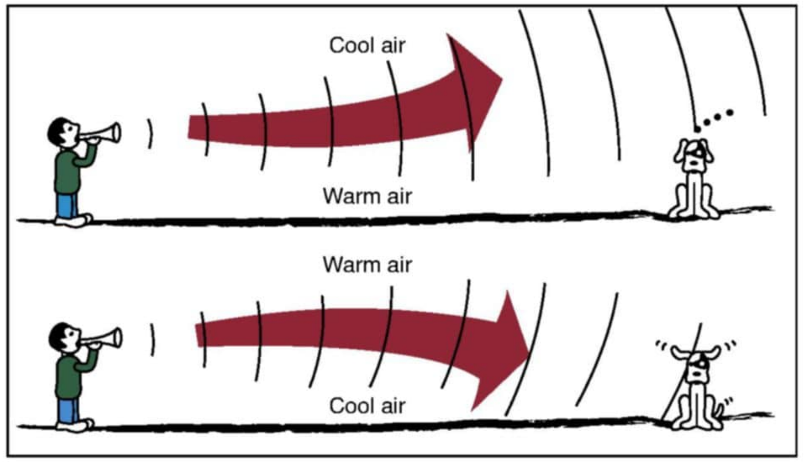


Figure 4: Change in temperature with height can cause refraction. (Source: Syllabus revision - Physics, www.piedpyper.com)

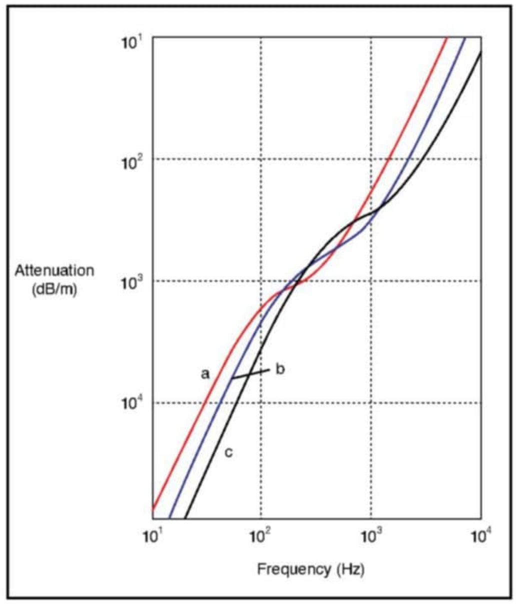


Figure 5: Sound absorbed by air causes attenuation, which is dependent upon both distance and humidity. (Source: H. Kutruff, "Room Acoustics," *Elsevier Applied Science*. Elsevier Science Publishers, Essex, 3rd edition, 1991)

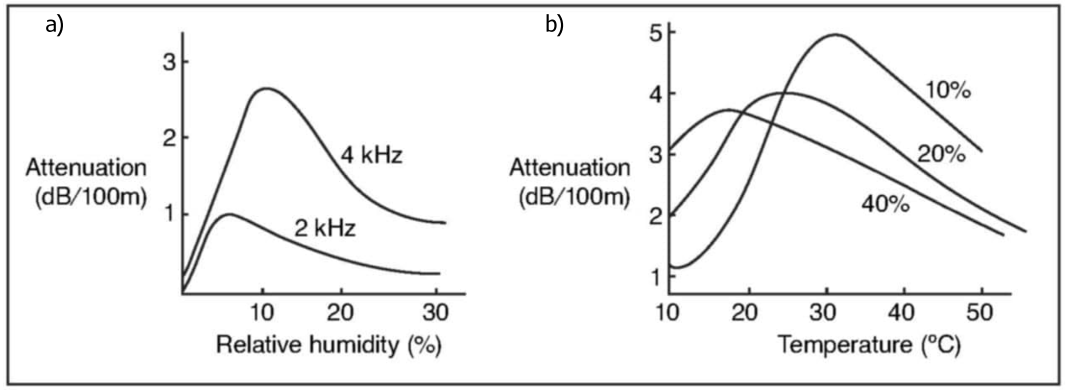


Figure 6: The effect of humidity alone upon air attenuation is significant. (Source: C. Harris, "Absorption of Sound in Air versus Humidity and Temperature," *Journal of the Acoustical Society of America*)

by air are illustrated in **Figure 6**. Figure 6a shows the effect of humidity for frequencies of 2kHz and 4kHz; Figure 6b shows the effects of temperature at 3kHz. Sound absorption by air is usually ignored where the sound travels only for small distances, but in auditoria, coliseums, and stadia, its effect can be significant, in terms of both sound level and frequency balance at the seats.

Practical Effects

In small listening rooms, the effects of atmospheric conditions (e.g., temperature and humidity) make only small changes in the frequencies of the room modes (a few percent). To investigate the effects in larger venues, I created an EASE model of a 120′ (W) × 70′ (L) ×24′ (H) auditorium and analyzed the RT, the STI, and the direct sound coverage from a speaker system at both normal temperature and humidity (68°C, 60%) and under hot-summer-day conditions without air conditioning (38°C, 90%).

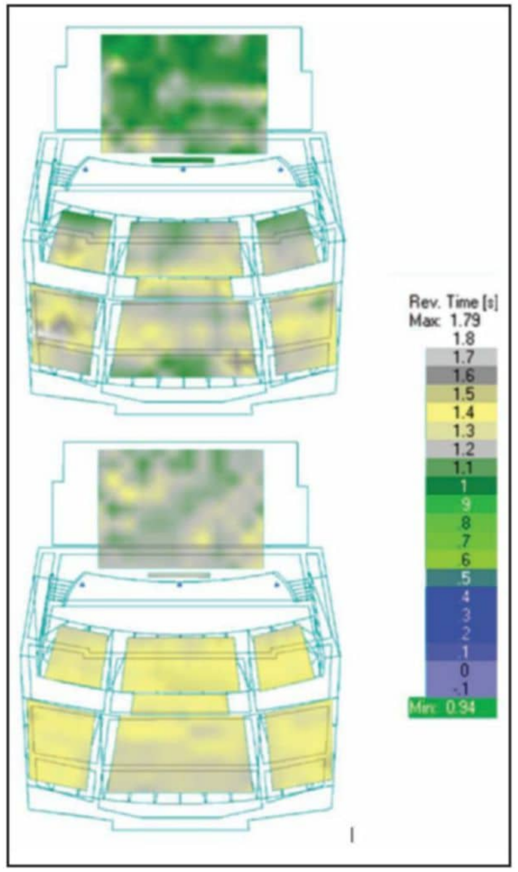


Figure 7: Higher temperature and humidity (lower) increase RT compared to normal conditions (upper).

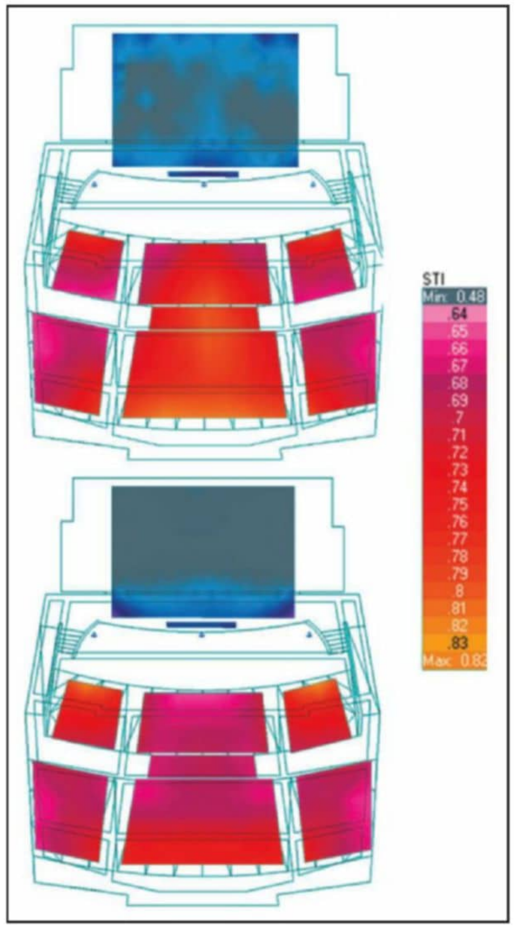


Figure 8: Higher temperature and humidity (lower) decrease STI.

Figure 7 shows that RT increases as temperature and humidity go up. Also, note from the RT maps (left-hand illustrations), the variation of RT from seat to seat increases with increased temperature and humidity. (The dark rectangle in the upper center is an area of absorption comparable to the stage and stage house.)

Figure 8 shows that speech intelligibility as indicated by STI decreases as temperature increases. Since STI depends greatly upon RT, this is to be expected.

Not only do higher temperature and humidity decrease the sound level at the seats, due to air attenuation, but as you can see in **Figure 9**, the change in c affects the coverage map by modifying the directivity of the speakers.

General Comments

OK, so what's the bottom line? The effects of air attenuation upon SPL and frequency response can be compensated by adjustment of sound system equalization, but the effects upon RT and STI cannot.

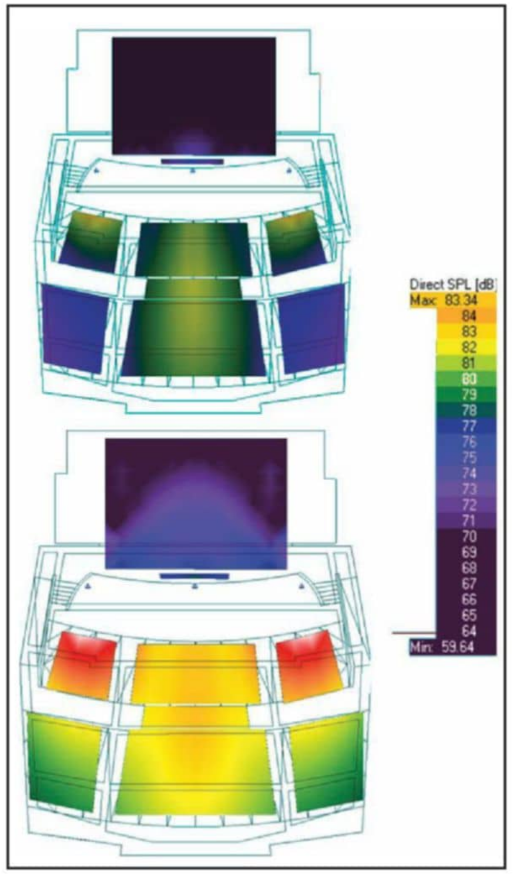


Figure 9: Higher temperature and humidity (lower) decrease direct sound level.

About the Author

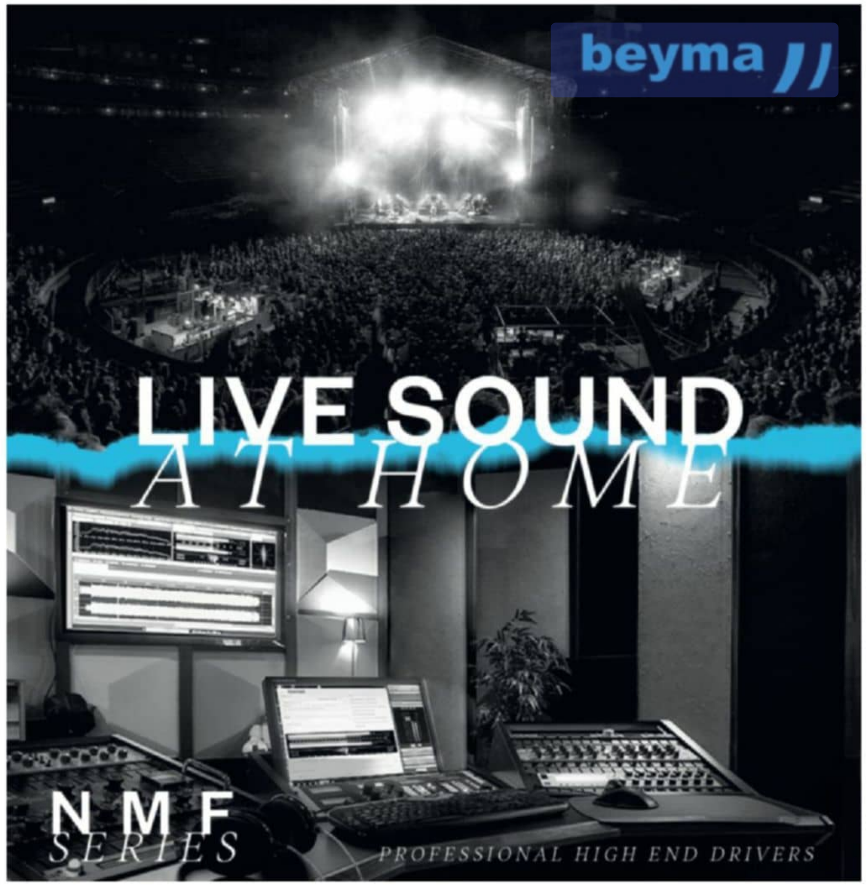
Dr. Richard Honeycutt fell in love with acoustics after his father brought home a copy of Leo Beranek's landmark text on the subject when Richard was in the ninth grade. Richard is a member of the North Carolina chapter of the Acoustical Society of America. Richard has his own business involving musical instruments and sound systems. He has been an active acoustics consultant since he received his PhD in electroacoustics from the Union Institute in 2004. Richard's work includes architectural acoustics, sound system design, and community noise analysis.

As mentioned in the April 2022 Sound Control article, "Frequency Response of a Listening Room," a major factor in the frequency response changes in auditoria is the additional absorption—mainly at high frequencies—due to the audience members wearing heavier clothing in winter. Even if they remove their coats during an event, many of the coats will be placed on seat backs, thus remaining in the venue and adding to absorption.

This same factor decreases RT and increases STI in winter, making for even greater seasonal changes in acoustical conditions than the ambient atmospheric effects alone. With most venues' temperature and humidity controlled year-round by HVAC systems, the effects of atmospheric conditions upon acoustics are greatly ameliorated.

As mentioned earlier, small venues (e.g., studios, production rooms, conference and video teleconference rooms) are unlikely to suffer significant effects from atmospheric conditions. But sound engineers for outdoor events have to take these effects into account for every performance.

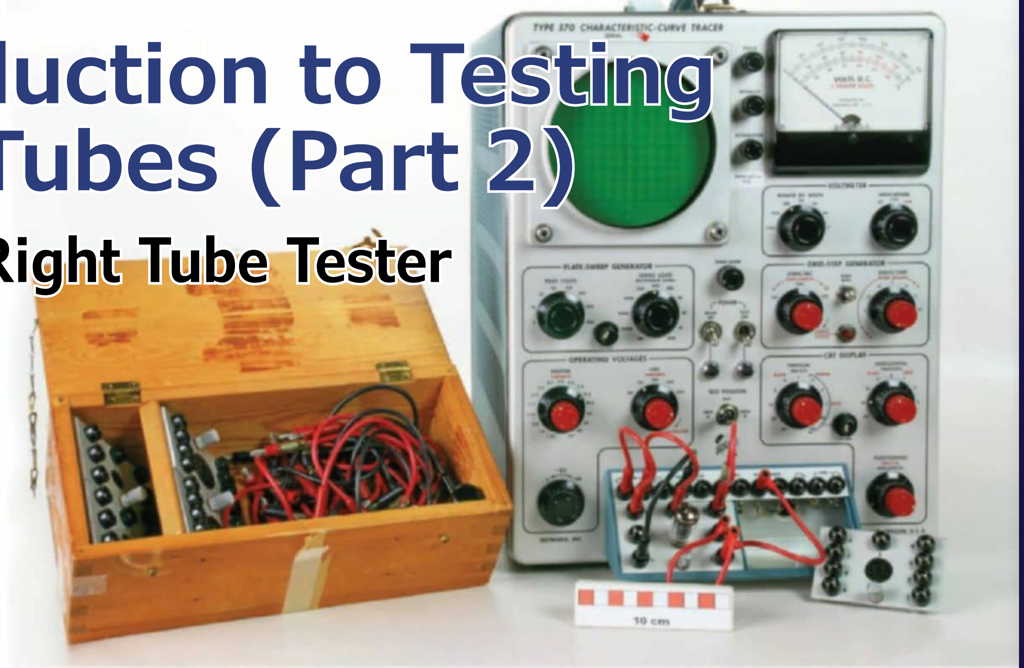
In addition to their adjusting levels and equalization, they must be aware of the surrounding terrain, since refraction can easily cause annoyance for adjacent property owners. Sometimes careful choice of speaker height and aiming can avert neighbors' annoyance, but atmospheric effects must always be taken into account for outdoor events!



An Introduction to Testing Vacuum Tubes (Part 2)

Choosing the Right Tube Tester

By
Mark Driedger



Part 1 of this article covered how tubes fail and wear out, and their key characteristics. In this continuation, the article discusses how tubes are tested, the different types of tube testers, and selecting a new commercially available tube tester.

So, how do you test a tube? Well, you can download all 428 pages of "Test Methods for Electron Tubes" (MIL-STD-1311D) and read it when you have problems getting to sleep. Or … you can use a tube tester. Tube tests generally fall into short and leakage tests, emissions tests, transconductance tests, curve tracing, and specialized matching tests. A given tube tester will often combine several tests.

Shorts/Leakage: Shorts should be tested before doing other tests to avoid equipment damage. An AC voltage of around 100V is applied through a neon bulb to one element and returned to either the adjacent elements or all other elements shorted together. The test is repeated for each element, usually by cycling through a series of switches.

Shorts are tested with the tube cold and leakage is tested with the tube heated. Sensitivity varies widely between testers. A typical short/leakage test circuit is shown in **Figure 1**, connected to check between cathode and grid 1.

Another way to test for grid leakage is to bias the tube and measure plate current. Then insert a high value resistor in series with the grid as shown in **Figure 2**. Bias voltage will shift due to the grid current flowing through the grid resistor, in turn causing a plate current change.

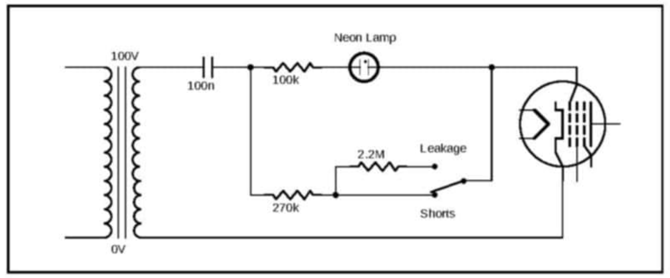


Figure 1: This is an example of a typical short and leakage test circuit (Heathkit IT-17).

Emissions test: An emissions test measures the cathode's ability to sustain a given amount of current and essentially tests the tube as a diode. An AC voltage in the range of 25V to 50V is applied to the cathode and returned to the plate and grids, as shown in **Figure 3**. The load resistor, R_L, limits current through the tube and the meter shunt resistor, R_S, adjusts the meter sensitivity. Both are adjusted for the specific tube being tested according to the tester's documentation or roll chart. The meter is calibrated with a pass/fail scale. A drop of 50% is usually taken as the end-of-service.

Emissions tests have numerous limitations. Since the first grid is closest to the cathode, most of the cathode current flows through it. Grid structures, especially on high gain tubes, are fragile and may overheat and distort or become gassy from too much current. Emissions testers have a push-to-test switch, and a rule of thumb is to limit measurement to 3 seconds to avoid grid damage. There is little science in the 3-second limit given the vast differences in tube types and testers. You might want to think twice about subjecting your far too expensive new-old stock (NOS) super-matched, cryogenically-treated 12AX7 to an emissions test on an unknown tester.

From the *Radiotron Designer's Handbook, 4th Edition* (page 94), "… the emissions test is a damaging test and should be performed as seldom as possible and then always very carefully." Testers vary widely in the amount of current they use for an emissions test. Alan Douglas' *Tube Testers and Classic Electronic Test Gear,* (page 4) measured a 6:1 range across a sample of testers.

Emissions tests are better at telling you a tube will not work, than confirming it will since they tell you nothing about the

grids' ability to do their job. Some testers let you disconnect one grid at a time. If the meter value changes, then that element has some (but not necessarily the correct) impact on current flow. However, this lengthens the test and increases the chances of damage.

Voltages are not regulated in AC emissions testers, so measured emission current will vary with the line voltage and with filament load on the (usually shared) transformer. Most testers have a line calibration feature that adjusts for these factors. Finally, there is no "emissions" spec on a tube datasheet. Each company specified pass/fail thresholds based on their experience and the specific circuit they employed.

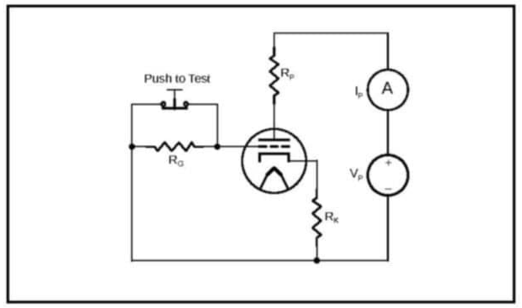


Figure 2: Here is an alternative method to measure leakage.

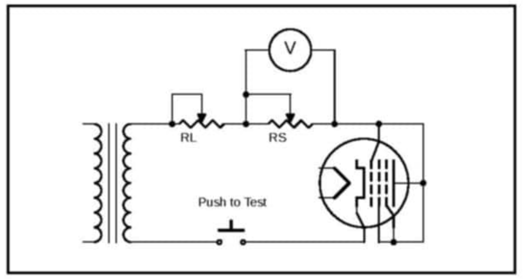


Figure 3: A Basic emissions test circuit is shown here.

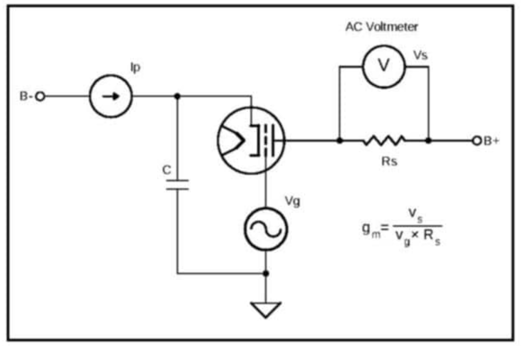


Figure 4: This schematic shows how to measure g_m.

About the Author

Mark Driedger has been experimenting with tube audio since 1980. He completed an MSc in electrical engineering at the University of Waterloo, Canada, and has worked in the telecom industry for more than 30 years in technical and executive roles. His other passions include woodworking, the guitar, and spending time with his wife, children, and grandchildren.

Transconductance tests: As you might recall from Part 1 of this article, transconductance is the ability of the grid to influence plate current and is an important measure of its performance as an amplifier. There are two accurate ways to measure g_m, and then there is the way that most tube testers do it.

The first accurate method is to set up the tube at a specific DC operating condition, and then do what the formula for g_m says—inject small grid voltage changes and measure the resulting plate current changes at a given fixed plate voltage. **Figure 4** shows how this is done in practice.

The current source sets a constant DC plate current. It is bypassed to ground for AC. The B+ source establishes a constant plate voltage. The AC plate current change is sensed through a small plate resistor R_s, typically 10Ω to 100Ω. The AC grid voltage, v_g , is in the audio range (1kHz to 10kHz, typically) and is small (50mV to a few hundred millivolts) to avoid saturating the tube. The resulting plate current change is also small. A tube with a g_m of 50mS and a 100mV of grid AC voltage results in 5mA of AC plate current or 50mV across a 10Ω sense resistor. This is within the capability of modern digital multimeters (DMMs), although accuracy and sensitivity are improved if the sense voltage is filtered and amplified, typically after being transformer isolated. The operating point can be varied to measure g_m over a range of conditions. A similar approach is used to measure μ but not discussed here.

A variant on this is to manually adjust the grid voltage up/down by small increments; record the grid voltage, plate voltage, and plate current; and then compute the parameters, much like we did in Figure 3 of the first part of this article. This voltage difference approach is tedious but works.

The second accurate method is to use a curve tracer and derive g_m from the curves at any desired operating point.

Both of these methods require high voltage, variable DC supplies and a sensitive, accurate AC voltmeter. In the heyday of tubes, these were bulky and expensive. So, most "transconductance" tube testers used an easily derived 60Hz AC voltage to sweep across a wide range of operating points and averaged the resulting pulsed DC plate current. Tubes and tube testers were big business, so this limitation was patented, turned into a marketing benefit, called dynamic transconductance testers, and touted as the best way to test a tube. **Figure 5** shows the basic principle.

If the tube under test were biased with a fixed DC voltage, then the average reading current meter would read zero, since the current through windings 1 and 2 is equal and opposite during each half cycle. Instead, the grid is driven with a full wave rectified pulsed "DC bias" from winding 4 added to an AC "signal" from winding 3. The meter responds to average AC plate current, and so measures something like transconductance but swept sinusoidally over a range of grid, screen grid and plate voltages.

Dynamic transconductance is a useful relative measure of tube aging and performance. It does not correspond to a true g_m reading at a given DC operating point, which you will understand by looking at how much g_m varies with plate current in Figure 2 of the first part of this article. The grid voltage is often quite large and can drive the tube into saturation and cutoff, further confusing the situation.

Curve tracers: Curve tracers sweep the voltage at two tube elements and measure the resulting voltage or current at another element. The result is plotted as a series of curves, matching the presentation of plate curves in tube manuals. The values of g_m, μ, and r_p are readily computed from measured curves at any DC conditions. No separate transconductance meter is needed.

The Tektronix 570 was the classical gold standard

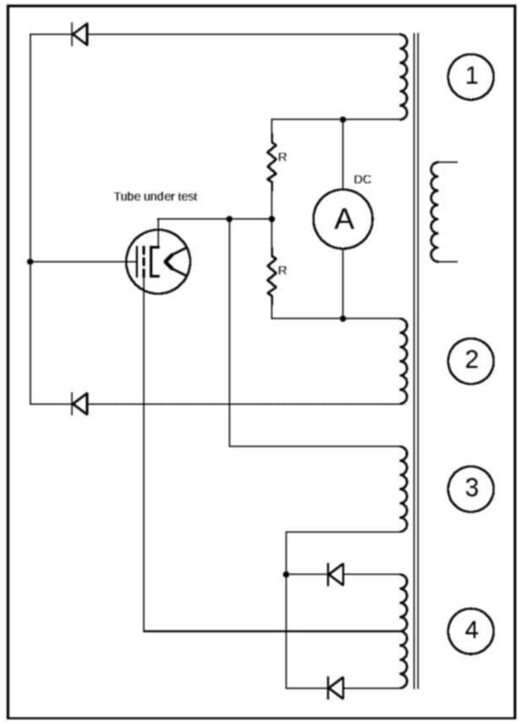
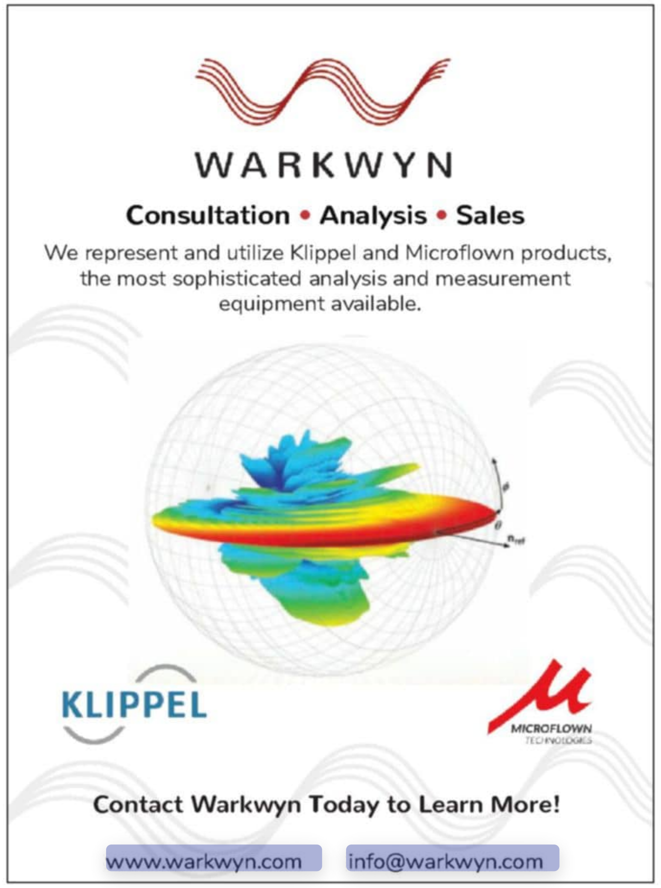


Figure 5: The basic principle of a dynamic mutual transconductance meter

(**Photo 1**). It is large and heavy at 75 pounds. The screenshot button is a Polaroid camera, and data points are hard to read accurately.

Today much smaller, lighter, and more accurate curve tracers are possible thanks to modern



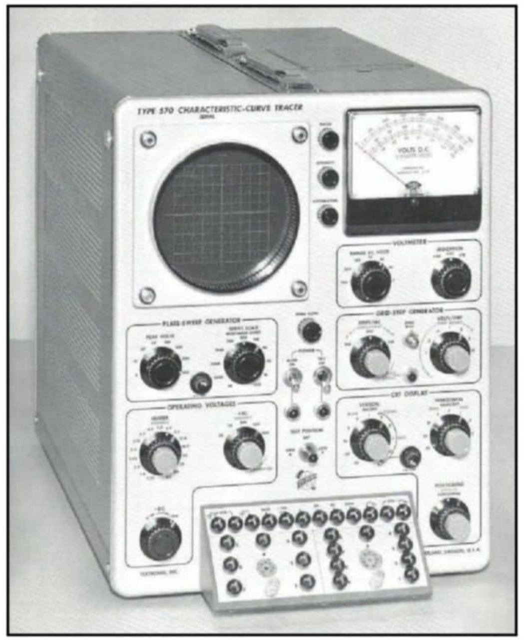


Photo 1: This is an example of a Tektronix 570 Curve Tracer. (Source: *Tektronix Operator's Manual*)

switching power supplies, fast and accurate analog-to-digital converters (ADCs) and digital to analog converters (DACs), and low-cost microcontrollers/displays. One of three methods are used to generate the variable plate and screen supply: programmable DC, half-wave rectified AC, or pulsed DC.

In pulsed DC units, power is applied just long enough to take the readings (typically less than 1 msec). Charge pumps can provide the very low power needed and the electronics fit in the palm of your hand. Pulse testers do not operate the tube at full power so bulb temperature and the demand on cathode emission are less. A weak tube may be able to deliver the short burst of current for the tester, but not enough for full power, continuous operation.

Matching: Tubes can be matched for DC performance, but it is easy to add a balance adjustment to push-pull circuits to compensate for tube variation. Many power amplifiers have built-in bias test points or meters (see my earlier article, "An Accurate Bias Meter for Push-Pull Tube Output Stages" in *audioXpress* for an example) and a means to adjust balance. External bias checkers temporarily insert a current meter in the cathode for the same purpose.

Matching AC operating points is generally done by measuring g_m, preferably at the intended operating point. Some testers allow a large batch of tubes to be tested, and then sort them into the most closely matched pairs or quads. Specialized matchers for small signal triodes sometimes use the tube under test in a Class A amplifier and measure gain, noise and other parameters.

Curve tracers can be used for matching and the modern ones have proprietary matching algorithms, for example comparing the RMS error between the plate curves being matched.

Microphonics and Noise: Many tube testers AC couple the plate to a headphone jack. The user can listen for noise and test for microphonic effects by introducing some form of shock or vibration. These are not very scientific but will weed out grossly microphonic tubes.

Selecting a Tube Tester

By now you will appreciate that tube testing is not simple! Picking a tube tester is complicated by the relatively few modern options available and the high prices that vintage models command.

A properly working vintage tester is a good choice for shorts, leakage, and emissions tests. However, realize that a "fail" on such a tester is not grounds for throwing out a tube that is still working in its circuit. A circuit may be able to tolerate higher leakage, or not need as much emission capability. Perform emissions tests as seldom and carefully as possible.

Personally, I don't put much faith in dynamic transconductance measurements and favor one of the methods to measure the true transconductance. Unfortunately, that leaves relatively few options for commercially produced testers. From my research, your options are the Amplitrex AT1000 (see Richard Honeycutt's "Amplitrex AT1000 Tube Tester" article in *audioXpress*), Maxipre (for small signal dual triodes only), Duovac (which uses the tedious manual voltage difference method), and Daedalus, a promising design by the Greek firm Tsakiridis Devices. Other "modern" commercial testers (e.g., the Orange Valve Tester, Sofia, and Vacutrace) have been discontinued.

The used market for vintage testers is active with many specialty resellers and lots of options on eBay, if you can restore them safely. Prices are high and you should research them carefully. The vast majority of these are dynamic transconductance or emissions testers. Alan Douglas provides a good survey of vintage testers in his book, *Tube Testers and Classic Electronic Test Gear.*

The tube tester DIY community is quite active and has good options from which to choose. Personally, I have built and use Steve Bench's RAT tester. It uses the AC signal method to measure g_m and μ. Ale Moglia provides a variation on the same principle that has a more sensitive and accurate plate current measurement circuit. And, the μTracer is a popular DIY-pulsed DC curve tracer. It is very compact, has a large community of users, and is available in kit form (see Resources).

DIY shorts, leakage and emissions testers are less common. Shorts and emissions testers are simple in theory but need complex circuits to switch tube elements in and out. Emissions testers are not useful without a good set of tube data that is specific to the test circuit. If you want to go this route, then Gary Steinbaugh's book, *Make Your Own Tube Tester and Electron Tube Equipment*, provides DIY designs and John Shelley describes an improved leakage tester in his *Glass Audio* article "A Better Tube Tester."

In Conclusion

I hope you have a better appreciation for why and how to test tubes. This is a complex subject and there is no silver bullet. The vintage market consists of equipment optimized around the technology of its day. While useful for sorting good from bad, in general they do not make accurate measurements. The new products and DIY projects show considerable innovation, but the market is not large enough to sustain many options. The saving grace is that the best judge of a tube is your circuit and its performance. As Robert Tomer says, it is best to avoid testing tubes as much as possible. However, that still will not dissuade the test equipment junkies such as myself from obsessing about how to do it well.

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Author's Note: The chapter on tube testing in Radiotron Designer's Handbook, 4th Edition *(RDH4) is a good companion to Robert Tomer's book. It is available on Pete Millet's site at:* www.tubebooks.org/ Books/intro_RDH4.pdf

Building a Guitar-Controlled Synthesizer

Frequency to Volts and Back

By
Ethan Winer

Ethan used this 1969 Fender Telecaster for the development of his guitar synthesizer. In this 2015 photo he is playing Tchaikovsky's "Rococo Variations for Cello and Orchestra" with the Danbury Symphony.

This is the second article in a fascinating DIY journey of a guitar-controlled, all-analog synthesizer project that will include multiple stages and modules. Following a Sample & Hold circuit designed to retrieve previous voltages that no longer exist, this article details voltage control and how the playing is converted to voltages and back to frequency.

In a previous article, I described my fascination with analog synthesizers and showed the "Time Machine" sample & hold circuit I designed for my current synth project that uses an electric guitar instead of a keyboard to play the musical notes.

In the article I explained that a core concept with all analog synths is voltage control, whereby the various qualities of sound (e.g., a filter's cut-off frequency or the rate and depth of vibrato) can be controlled automatically by voltages as well as manually with potentiometers. This lets you program changes to the volume and other sound qualities that happen every time a note is played, without having to turn the knobs.

The most important voltage-controlled element in an analog synthesizer is its oscillator—the circuit that actually creates the musical notes. But a guitar synthesizer also needs to assess the incoming frequency. When a note is played on a guitar, the frequency of the note must be assessed and converted to a corresponding voltage. That voltage then directs a voltage-controlled oscillator (VCO) to play the same note, but with the quality of a synthesizer rather than a guitar. (Typical oscillator waveforms include square, pulse, and sawtooth.) It's also possible to transpose notes so music played in the key of E sounds in a different key. But this is the core concept. The common term for these conversion circuits is Frequency to Voltage (F2V) and Voltage to Frequency (V2F).

Dedicated F2V IC chips are available, though it's pretty simple to do this manually. As with my previous Sample & Hold article, the circuits shown here were developed using the LTspice virtual circuit simulator. This free program from IC maker Analog Devices offers a fully stocked parts bin with a virtual oscilloscope and other test gear. You just draw the schematic, then click Run to watch it work. Once the circuit performs as expected, you can design a PCB, buy the parts, and build it for real.

Frequency to Voltage

Figure 1 shows a 555 timer chip that outputs a 2mS pulse every time the input signal goes in the negative direction. I used a squared up sine wave as the source because it's easier to specify the frequency than for square waves using LTspice's Pulse generator. The output pulses from the timer charge capacitor C4 through resistor R5. At high frequencies, the 555's fixed-width pulses arrive more often than at lower frequencies, so the average output voltage is higher.

Figure 2 shows the oscilloscope display when the source is 100Hz, and **Figure 3** shows the same for 200Hz. The brown traces are the 555 timer's output pulse stream and the yellow traces are the averaged output voltage. At both frequencies it takes time for the capacitor to reach its final averaged voltage, and the output also contains ripple instead of being steady DC. The ripple can be reduced by making the capacitor larger, but that increases the averaging time! The balance between time to average and the ripple in the output is a basic problem with all frequency to voltage converters.

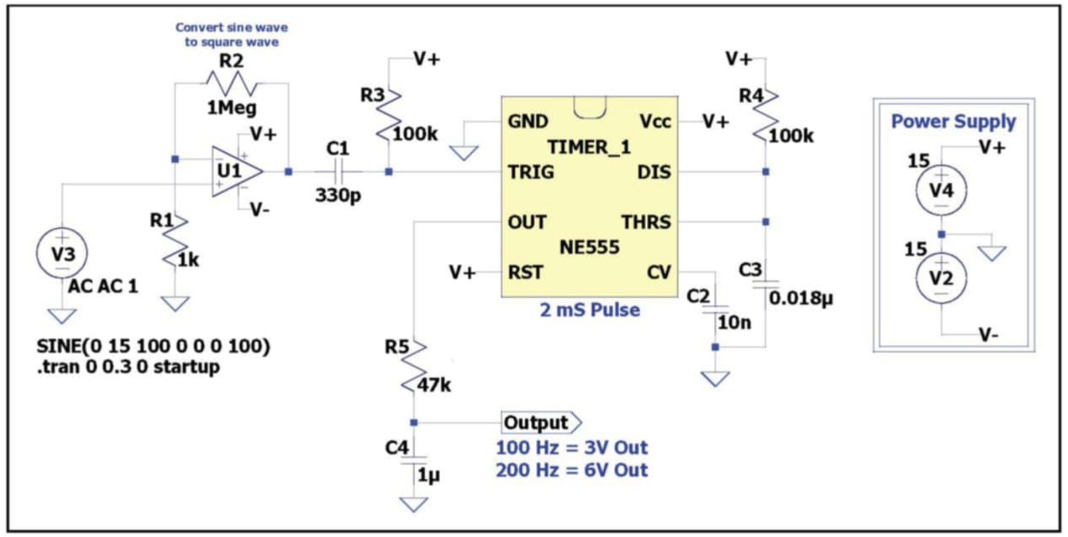


Figure 1: A basic Frequency to Voltage (F2V) converter uses a timer IC to generate pulses having a fixed duration, which are then averaged by a resistor and capacitor.

Period to Voltage

A better way to convert frequency to a corresponding voltage is to measure the time span between pulses, or the period of the incoming frequency. By measuring period instead of frequency the result can be known in the very first cycle. This is the approach I used for the circuits shown in **Figure 4**. So rather than calling them F2V and V2F, we'll use P2V and V2P. In the glory days of DOS, in the 1980s and early 1990s, I owned a software company and was the chief programmer. So I know the value of comments that explain how computer code works, and likewise I added many comments to the circuits shown here to expand on the descriptions that follow. In order to fit them, some of the comments are in a font too small to easily read. Under Project Files is a link to the full schematic as a PDF, which can be enlarged so you can read everything clearly. The LTspice file, also available in the Supplementary Material section of the *audioXpress* website, has all the comments as well.

As with the F2V in Figure 1, a sine wave source is sent through a high gain op-amp to create square waves suitable for triggering a 555 timer. But unlike F2V circuits that output a rising voltage at higher frequencies, a P2V's output voltage becomes smaller because the period between cycles is shorter. This is easily countered in the V2P's design, but the

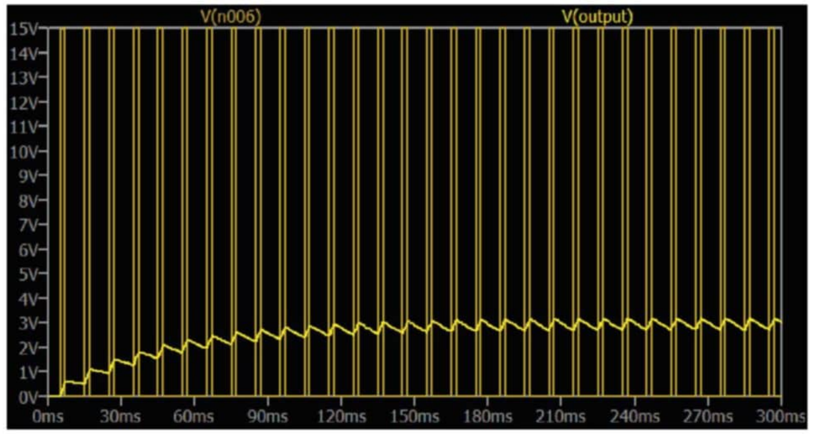


Figure 2: At 100Hz, the timer's pulses are about one-fifth the duration of each cycle, so the output voltage is one-fifth the 15V power supply, or 3V.

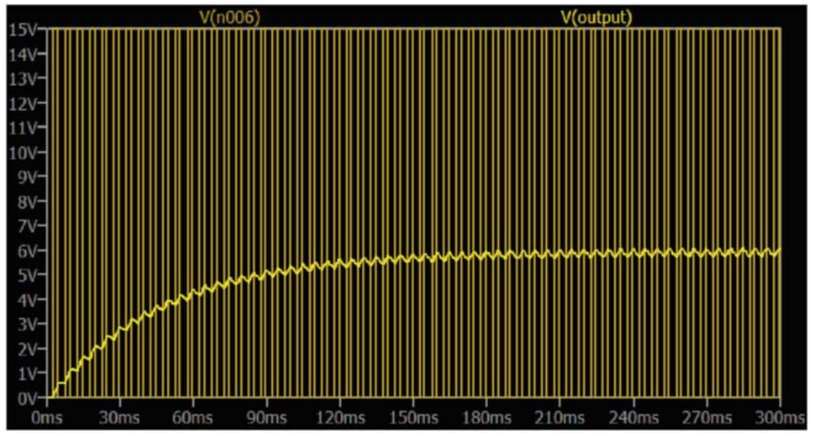
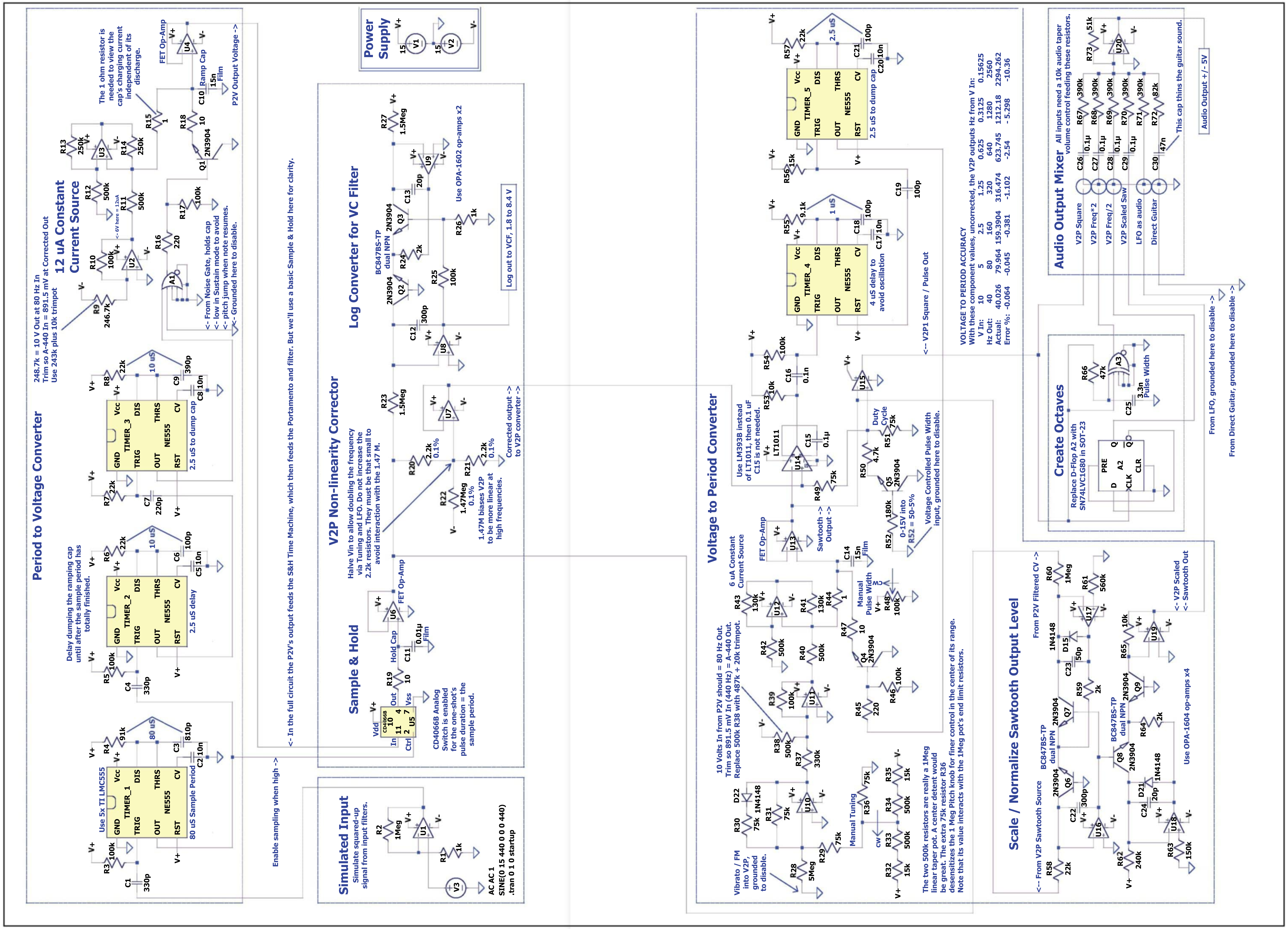


Figure 3: At 200Hz, the timer's pulses arrive twice as often, so now the output at 6V is twice what it was for 100Hz.

Figure 4: The entire circuit for converting period to voltage and back is fairly complex, though some portions are for support rather than core operations as explained in the main text.



synthesizer's voltage controlled filter (not shown) requires a voltage that rises at higher frequencies. So a logarithmic converter is used to generate the reciprocal 1/V needed by the filter. Another log converter serves as a divider to counter the falling voltage of the V2P's sawtooth wave's output. Two other auxiliary circuits multiply and divide the V2P's square wave frequency to generate simultaneous higher and lower octaves.

Circuit Details

The basic concept for reading the period of a waveform's frequency is to start charging a capacitor when an input cycle begins, then "sample" the voltage across that capacitor when the next cycle starts. At low frequencies the capacitor's voltage rises more than at high frequencies simply because it was allowed to charge up for a longer time period. The sampled voltage also needs to be remembered, or "held," at a steady level until the next cycle ends. Hence the name Sample & Hold.

For clarity, this circuit uses a simple Sample & Hold rather than the more complex version shown in my previous article (*audioXpress*, April 2022) from the full guitar synthesizer. Working our way from left to right, then top to bottom, I'll explain each circuit section of Figure 4 in turn.

Five separate 555 timer ICs are used in monostable mode to generate positive voltage pulses of varying duration. This popular timer IC is triggered to begin a cycle each time its input drops below one-third of the power supply voltage. As each incoming wave cycle goes from positive to negative, the first timer's output goes high for 80 microseconds (µS) to establish the sample period for the CD4066B analog switch directly below. This timer also triggers a series of events: first a brief delay to allow the "ramping" capacitor C10 to stabilize at its final value, then another 2.5µS to discharge the cap back to zero volts to begin the next cycle. This capacitor is charged by a constant current source (CCS) rather than a resistor because charging times with a resistor aren't perfectly linear. With a CCS the capacitor reaches exactly half the voltage when the incoming frequency rises one octave, as shown in **Figure 5**.

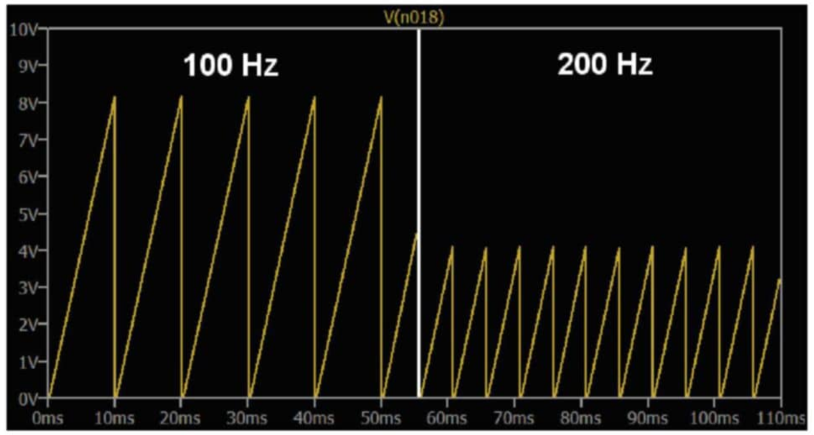


Figure 5: The "ramping" capacitor is charged by a constant current source (CCS) for the duration of one cycle of the incoming frequency. When the incoming cycle ends, the cap is reset to zero volts. Therefore, at lower frequencies the capacitor reaches a higher voltage because it was charged for a longer period.

Note OR gate A1 that allows holding the ramp capacitor at zero volts in Sustain mode. Most synthesizers let you use a foot switch to emulate the Sustain pedal on a piano. In Sustain mode the current note continues to play even after the guitar's output stops, with the Sample & Hold continuing the current note's voltage. This circuit has been altered to function on its own, separate from the rest of the entire synthesizer, so the second OR input is grounded to disable it.

Also note that NPN transistor Q1 is reversed from its usual orientation where the emitter would be grounded with the collector connected to discharge the ramp capacitor. When a transistor is used backwards like this its gain is only 1, but it brings the emitter much closer to ground than the usual configuration, which in turn increases the linearity of the P2V conversion. However, these operations are never perfectly linear, so a teensy offset voltage is applied at op-amp U7.

The Sample & Hold circuit is based on an analog switch that opens and closes under voltage control, followed by a capacitor that holds the voltage applied when the switch was briefly closed. It's important to use a high-quality film capacitor here because ceramic capacitors have memory effects that make them nonlinear. Ceramic caps can also "leak" some of their charge. For the same reason, an FET op-amp is used to buffer the cap's voltage because the higher bias current of a typical bipolar op-amp would drain the capacitor over time making the note go sharp or flat in pitch.

The Sample & Hold's output also feeds the logarithmic converter mentioned earlier that's needed for the voltage-controlled filter elsewhere in the synthesizer. This circuit is adapted from Texas Instruments (TI) Application Note AN-30, which you can download from the link in Resources. For this LTspice emulation, common 2N3904 transistors are used to generate the logarithmic result. But the real circuit will use dual NPN transistors, where both are on a common substrate. This ensures better linearity in the conversion because ambient temperature changes will affect both transistors equally. Obviously, temperature is not a factor in a circuit emulation!

The main portion of the V2P converter is near the middle of the third schematic row, and it's more or less a reciprocal to the P2V circuit. Like the P2V, it also charges a ramping capacitor (C14) with a CCS, which is reset when the cap reaches the incoming P2V control voltage via comparator U14. The comparator then triggers a pair of 555 timer chips that reset the cap to zero volts using another reversed transistor, Q4. A second comparator, U15, generates a square wave output, and its reference voltage can be changed either manually or via voltage control to vary the duty cycle to become a pulse wave.

Earlier I mentioned that synthesizers let you transpose notes to play in a different key, and most also let you vary the pitch for vibrato and FM effects. So only 6 microamps (µA) of current is applied to allow shifting the pitch up or down a full octave via external voltage control. If the same 12µA was used, the cap would try to exceed the 15V power supply limit at very low frequencies.

Since the voltage at the ramping capacitor is a sawtooth, we can use that for one of the V2P oscillator's outputs. But the voltage varies directly with frequency, making higher notes softer and softer. As with ramp capacitor C5 in the P2V converter, C14 in the V2P circuit is also charged by a CCS. And as with C5, the highest voltage reached before its reset halves with each doubling of frequency. So to normalize the sawtooth wave's output level to remain constant versus frequency, another logarithmic converter divides the sawtooth's falling voltage by the P2V's output voltage that is also falling. For example, 10 divided by 5 is the same as 6 divided by 3.

LTspice does not have a potentiometer component, so in the V2P converter are notes to replace resistors with pots or trimpots, for example to set the pulse width manually or to fine tune the pitch. Pulse width changes the duty cycle of the square wave output, which makes the tone thin and reedy sounding as the pulses get more narrow. This circuit shows ways to control the width both manually and via voltage control. The manual potentiometer is not connected, but could be through another 180k resistor. In case it's not obvious, this synthesizer is still in development, though most of the modules are complete and fully functional.

The last two sections are the frequency doubling and halving, using basic logic circuits rather than separate V2P converters. Dividing a frequency by 2 is simple using a D ("Data") flip-flop. Each rising edge at the Clock input to A2 toggles the Q and Q-bar outputs once. So it takes two cycles at the Clock input to complete one cycle at the outputs.

To double the frequency we instead use an Exclusive OR gate. In this case, each rising and each falling edge of the incoming square wave generates a new pulse at the output. Note that this output has a fixed pulse width, so the duty cycle changes with frequency becoming thinner sounding

About the Author

Ethan Winer has been an audio engineer and professional musician for more than 45 years. His Cello Rondo music video has received nearly 2 million views on YouTube and other websites, and his book *The Audio Expert* published by Focal Press, now in its second edition, is available at amazon.com and Ethan's own website ethanwiner.com. Ethan is also a principal at RealTraps, a US manufacturer of high-quality acoustic treatment.

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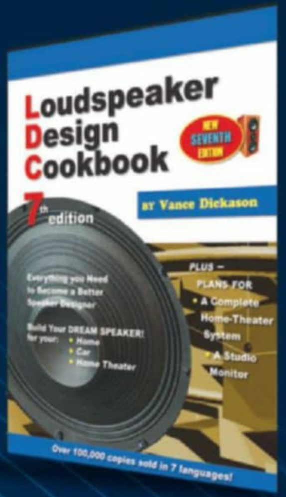

for notes at a lower pitch. This is not necessarily a bad thing for a synthesizer as it retains more body at higher notes keeping them from becoming too thin and buzzy sounding.

The audio output mixer is simple enough to be self-explanatory. I connected only one of the output waveforms, and for now used fixed resistors to set the volume levels. In the final design each signal source will have its own 10kΩ audio taper volume control, as noted in the schematic comments. The 0.1µF capacitors are needed because the V2P oscillator outputs go up from 0 volts, but audio signals must be centered around 0 volts going both positive and negative. ax

Author's Note: In my previous articles I mentioned my friend Leo Taylor, who in the 1970s taught me much of what I know about audio circuits. I also need to acknowledge my current mentors, Bill Eppler and Julia Truchsess. Both are black belt-level electronics geniuses, and exceedingly nice people. The core Period to Voltage and Voltage to Period converters are Bill's design, and Julia helped with many of my recent projects published in audioXpress. *I could not have designed the Null Tester (June, 2019) without her expert guidance. Julia's Pragmatic Designs company website contains a huge amount of fun and interesting content, including all of the musical instrument products and accessories she's designed over the years.*

Project Files

To download additional material and files, including the LTspice circuit for the simple Frequency to Voltage converter and the LTspice circuit for the complete Period to Voltage to Period converter, visit:
http://audioxpress.com/page/audioXpress-Supplementary-Material.html

Resources

LTspice,
www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

LTspice online support forum, https://groups.io/g/LTspice

Texas Instruments Application Note AN-30, Log Converters,
www.ti.com/lit/pdf/snoa641

Julia Truchsess, Pragmatic Designs, https://pragmaticdesigns.com

E. Winer, "Building a Guitar-Controlled Synthesizer: The Sample & Hold Time Machine," *audioXpress*, April 2022

E. Winer, "Building a Null Tester Device," *audioXpress*, June 2019,
https://audioxpress.com/article/you-can-diy-building-a-null-tester-device

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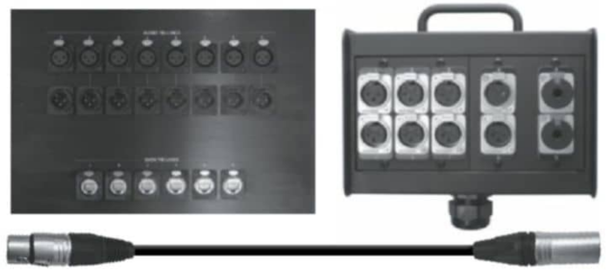

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Graphical Analysis of Class-A Amplifiers

Developing a Love of Designing Hollow-State Electronics

Learn how to design an audio amplifier and achieve the best performance out of existing tube-based circuit designs using the graphical analysis method.

By
Richard Honeycutt

Many hollow-state electronics enthusiasts started out as hobbyists by building equipment either from kits or from articles in publications such as *Glass Audio* or *audioXpress*. The combination of experience and curiosity has often led to a desire to modify existing circuit designs.

During my years teaching electronics to college students, I noticed that my best students were those who had embraced electronics—often hollow-state electronics— through these avenues. One such student began modifying commercial guitar amps when he was in high school. Then after college graduation, a few more years in avionics repair, and a few more years in pager-tower maintenance, he returned to his former love and opened a boutique guitar amplifier shop. Another student preferred to design/build amps from old Hammond organ or tube PA amp chassis, tweaking them to achieve the desired sound.

At some point, many tube enthusiasts want to learn how to design an amplifier from scratch. In the days before computerized circuit analysis software (e.g., LTSpice), the most straightforward way to design a hollow-state amp was the graphical method.

Using information obtained from the datasheets listed in tube manuals, the designer could be reasonably sure that when (s)he breadboarded the circuit, its performance would closely match the target gain, maximum output signal level, and distortion behavior, while the tubes operated within their safe voltage and power limits. The design decisions involved: choice of tube(s) to be used; desired input resistance or impedance; load resistance to be driven; B+ supply voltage; voltage gain; and distortion behavior.

The choice of tubes is discussed in the Hollow-State articles published in *audioXpress* in April, May, and June 2013. One simple method of choosing tube types is to use the same types as a similar piece of equipment that you respect.

The desired input resistance or impedance depends upon the signal source: dynamic or capacitor microphones, phono cartridges, guitar pickups, or other electronic devices. The input resistance for your design should typically be about 10 times the output resistance of the source. (An exception is moving-magnet phono cartridges, which are usually designed for optimum performance when driving a 47kΩ load.) In some cases, input transformers are necessary to provide the desired input impedance.

The input resistance of a common-cathode stage is usually determined by the value of R_G, the grid-leak resistor. To void decreasing gain and increasing distortion, the plate resistor of a given stage should be 5 to 10 times smaller than the load resistance. Sometimes a cathode-follower output stage is needed in order to convert the output resistance to a value low enough to properly drive the load resistance. In other cases, an output transformer is needed.

The remaining three design decisions are strongly influenced by tube characteristics and biasing. We will examine ways of using graphical analysis to optimize the bias of an RC-coupled or transformer-output tube stage.

RC-Coupled Stages

The basis of graphical analysis is the characteristics graphs provided in the tube datasheet. These comprise three types of graphs: the plate characteristic (plate current plotted

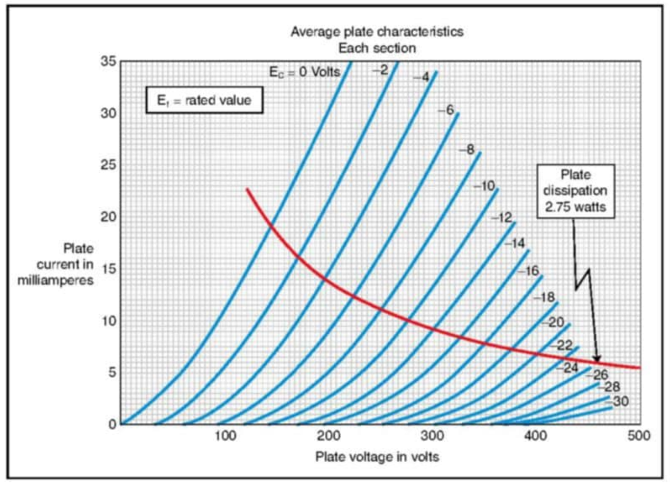


Figure 1: The plate characteristic of a 12 AU7 shows the effects of plate voltage and control-grid current upon plate current. (Ef is filament voltage.)

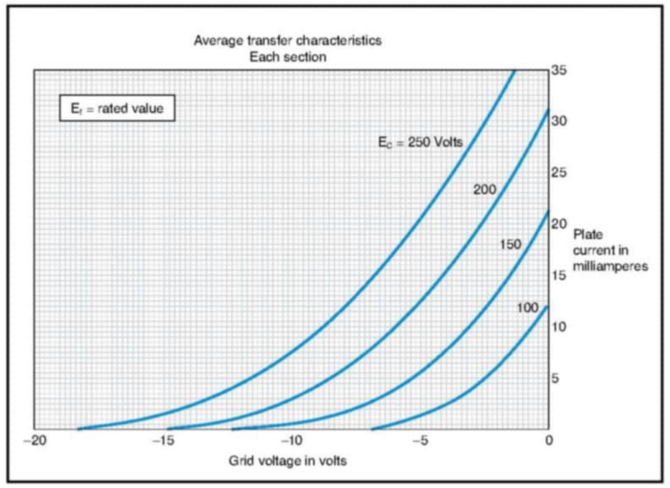


Figure 2: The transfer characteristic (sometimes called the "input characteristic") is another way in which the effects of plate voltage and control-grid voltage on plate current.

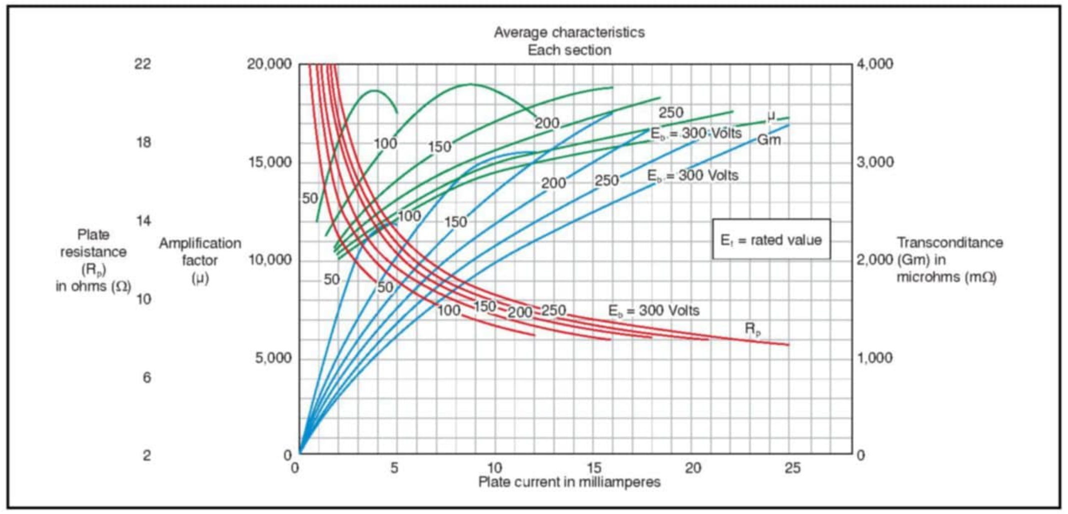


Figure 3: The average characteristics graph shows the variation of plate current upon μ, plate resistance, and transconductance.

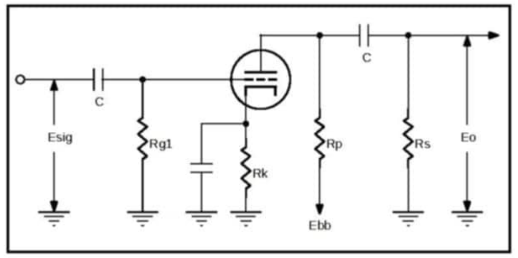


Figure 4: This circuit represents a single-stage RC-coupled triode amplifier. (E_{bb} denotes the B+ voltage. E_{sig} and E_O are the input and output signal voltages, respectively.)

About the Author

Dr. Richard Honeycutt bought a *Popular Electronics* magazine from the rack at a bus station in 1960. It contained an article on building a transistorized audio amplifier, which captured his interest. He followed up by subscribing to several electronics magazines. To avoid the cost of parts, he built up a "junk box" by disassembling trade-in TVs from his uncle's furniture store. His dad bought him the Van Valkenburg, Neville, and Nooger Basic Electronics book set, so he learned about tube circuits as well as transistors. He started repairing electronic devices about 1965, earning his First-Class Commercial FCC license in 1969. He has worked part-time in broadcast radio engineering and audio electronics repair since 1968, in addition to full-time work in acoustical and audio system design, plus a 20-year stint teaching electronics at the college level.

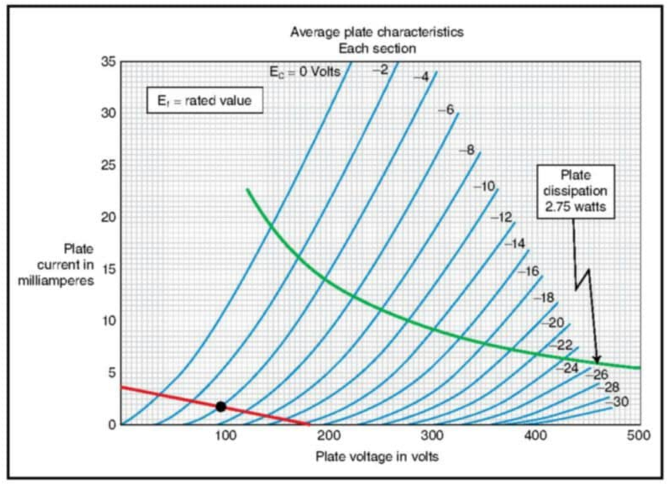


Figure 5: The DC load line is shown in red, and the Q-point is the black dot.

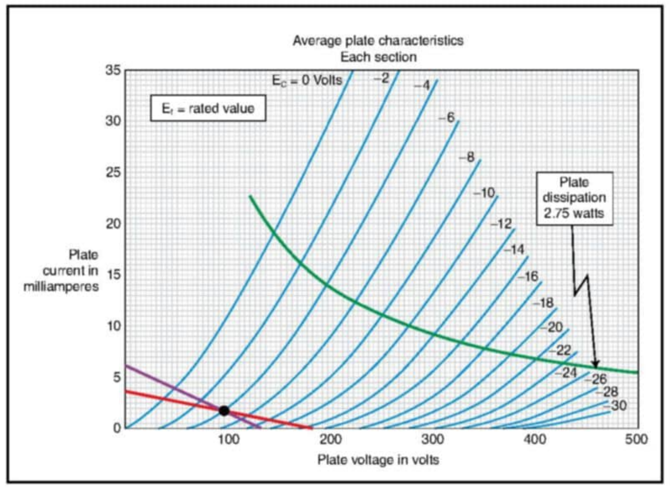


Figure 6: The AC load line shown in purple is steeper than the DC load line for an RC-coupled stage.

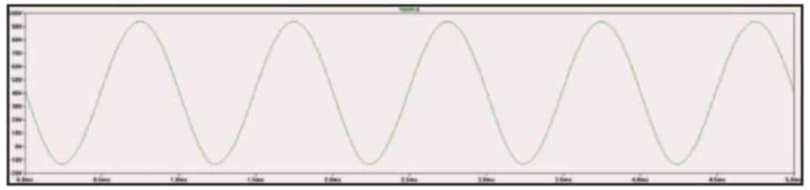


Figure 7: The DC load line has only 2.35% THD, and an amplitude of 105V.

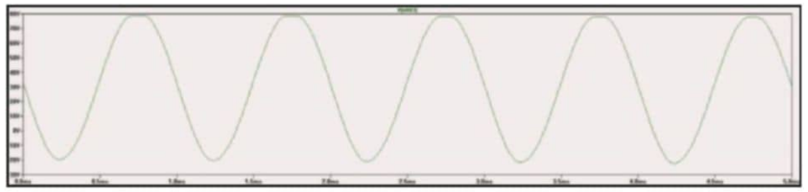


Figure 8: The AC load line has more distortion (4% THD) and an amplitude of 105V.

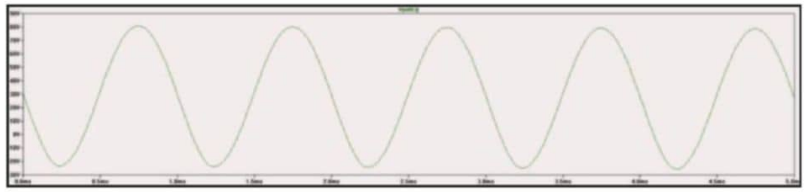
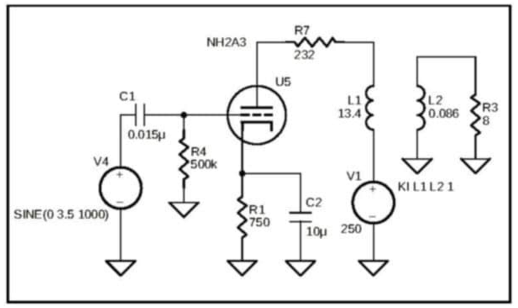


Figure 9: With B+ increased to 300V, maximum amplitude remains about 105V, but THD decreases to 2.4%.

Figure 10: This single-ended Class A 2A3 stage is transformer-coupled to the speaker.



versus plate voltage, with control grid bias as a parameter); the input or transfer characteristic (plate current plotted versus control grid voltage with plate voltage as a parameter); and average characteristics (gain, plate resistance, and/or transconductance plotted versus plate current with plate voltage as a parameter). **Figures 1-3** show these graphs for a 12AU7 dual triode. **Figure 4** shows the circuit of the RC-coupled stage.

We begin our analysis by constructing a DC load line. This line defines all the possible combinations of plate current and plate voltage for a tube having a given value of B+ voltage and plate resistor. **Figure 5** illustrates one possible DC load line. The horizontal intercept represents the highest possible instantaneous plate voltage: 180V. The vertical intercept shows the highest possible instantaneous plate current: the B+ voltage divided by the value of the plate resistor (180V/510kΩ= 3.59mA). Note that the entire load line falls below the 2.75W maximum plate dissipation curve, as it should in order to avoid tube damage.

The quiescent (no-signal) plate voltage and current will be determined by the control-grid bias, which in turn is set by the choice of the cathode resistor value.

An approximate value for the Q-point (or quiescent point) can be set at the midpoint of the DC load line, as shown in Figure 5. Since the Q-point falls on the -4V grid voltage curve, the cathode resistor value must be 4V/3.59mA=1114Ω. We would probably use a 1.2kΩ resistor.

In operation, an audio amplifier's behavior is defined by the AC load line, which includes the effects of the input resistance of whatever load the

amp stage is driving: in this case, the value of the grid resistor R_S of the following stage. If we make this 510kΩ like the plate resistor of the present stage, the AC load line will extend from a vertical intercept of $R_S||R_P$ (the plate resistor paralleled with R_S) through the Q-point, and on to the horizontal axis. (See the purple line in **Figure 6**.)

Since the AC load line is steeper, the Q-point is no longer centered, and we can expect more asymmetrical (even-order) harmonic distortion. Thus we see that the load resistance that an amp stage drives affects the distortion performance.

Increasing the B+ voltage would decrease this effect, as would designing the amp so that the input resistance of the following stage or equipment is significantly higher than the value of R_P.

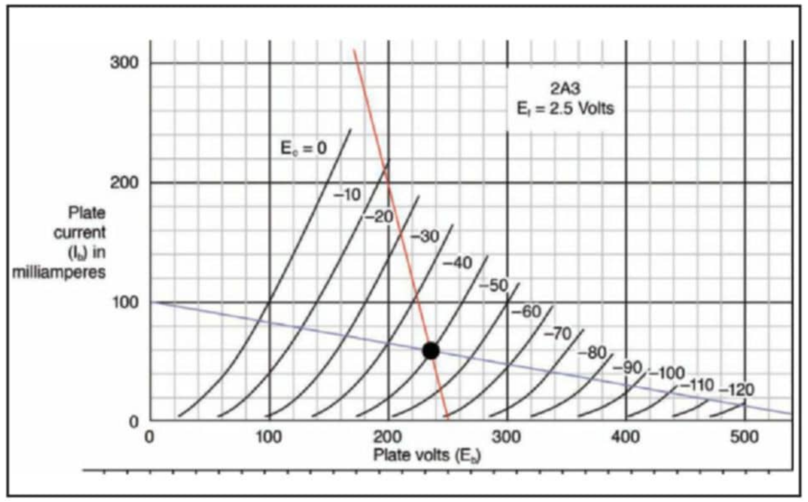


Figure 11: The DC (red) and AC (blue) load lines for an output- transformer-coupled stage are very different from those for an RC-coupled stage.

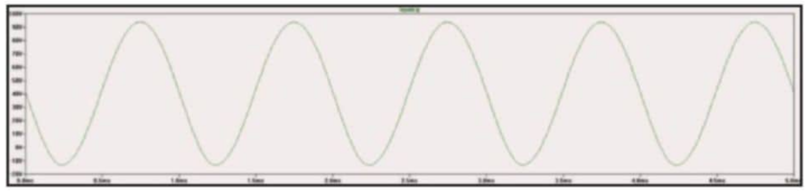


Figure 12: The output-transformer-coupled 2A3 Class-A triode stage produces a clean output wave (THD under 5%) when operated at the Q-point suggested in the data sheet.

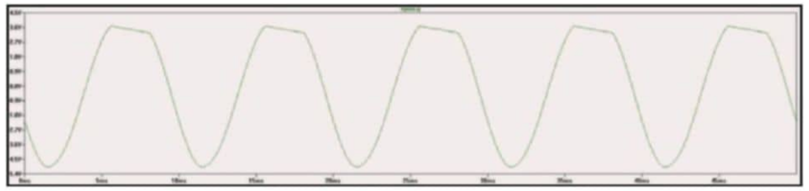


Figure 13: Changing to a 4Ω load changes the AC load line and causes clipping.

Let's look at the simulated waveforms that LTSpice gives us for three cases:

- No load connected (RS=∞) (**Figure 7**)
- As shown by AC load line (R_S=R_P) (**Figure 8**)
- As shown by AC load line (R_S=R_P), with the B+ increased to 300V (**Figure 9**).

Stages with Transformer-Coupled Outputs

The construction and appearance of load lines are different for triode stages with transformer-coupled outputs. **Figure 10** shows an LTSpice model of a single-ended Class A 2A3 triode stage with a transformer-coupled output.

The DC load line extends from the horizontal intercept at the B+ voltage to the vertical intercept at the maximum possible plate current:

($iP_{max}=V_{B+}/R_{XP}$).

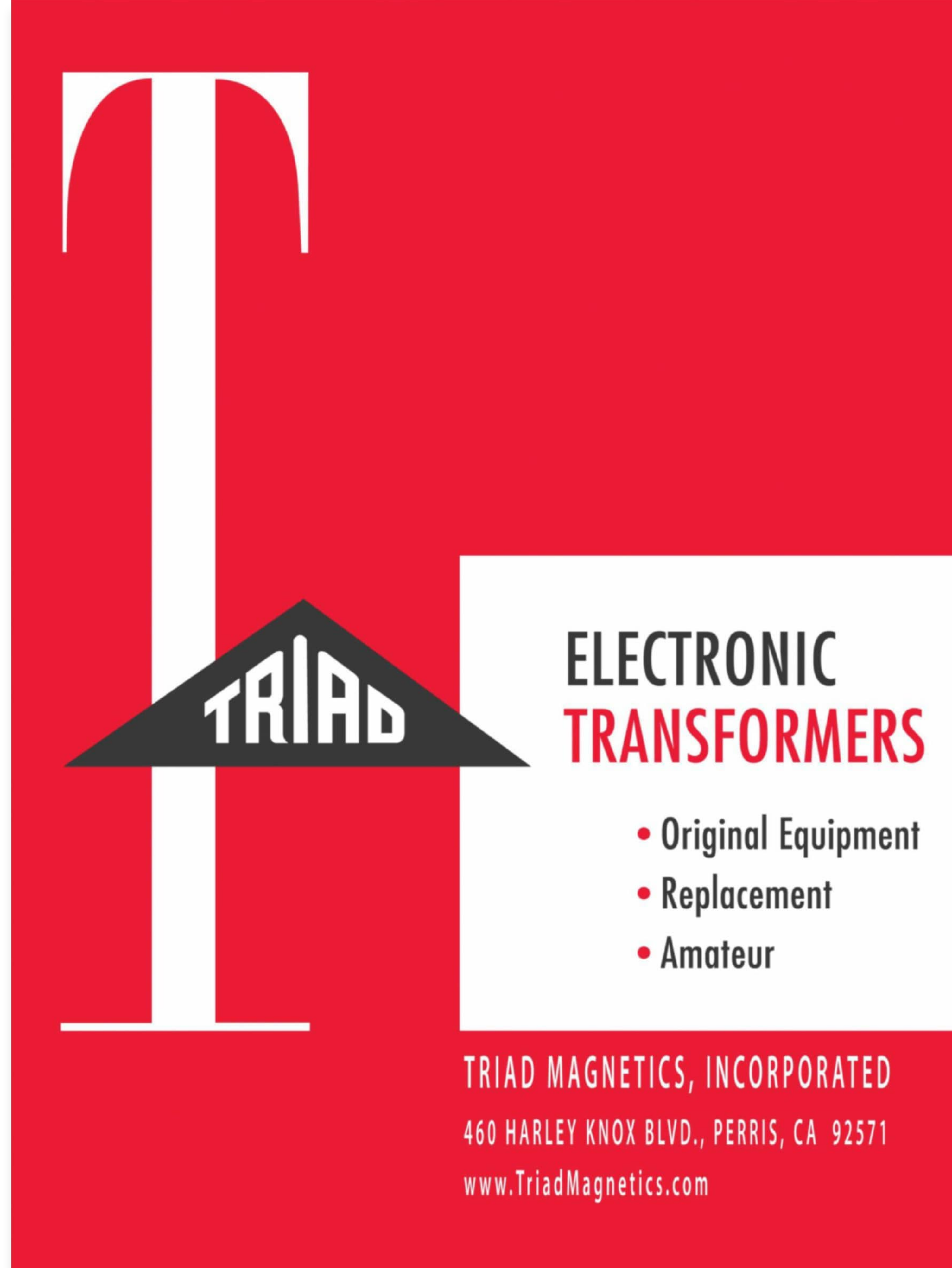
In this case, R_{XP}, the resistance in series with the plate, is the transformer's primary winding resistance of 232Ω (R7 in the model). The DC load line is shown in red in **Figure 11**. Its vertical intercept would be 1.08 amperes (A), which is above the top of the graph.

The Q point is set for a quiescent plate current of 60mA, per the recommended Class-A operating conditions on the Tung Sol datasheet (**Figure 12**). The AC load line shown in blue is drawn from a vertical intercept equal to (V_{B+}/R_{refl}), through the Q point, to the horizontal axis.

Audiophiles have often said that tube amps could drive lower-impedance speaker loads than those for which they were designed, while solid-state amps were prone to output transistor shorts from overheating. Although this is true from a hardware-protection standpoint, it does not follow that connecting paralleled speakers to a tube amp has no undesirable consequences.

If the 2A3 amp we have been discussing were connected to two paralleled 8Ω speakers, the resulting 4Ω load would be reflected to the primary of the output transformer as half the load resistance that the single 8Ω speaker would present. This would dramatically change the AC load line, resulting in a clipped output wave, as shown in **Figure 13**.

The clipping on positive peaks represents almost 15% THD. The increase in distortion due to connecting paralleled speakers would not be nearly as large if the power amp used negative feedback; in fact, overloading a Williamson power amp by a factor of 2 or even more may not create an audible difference in the sound.



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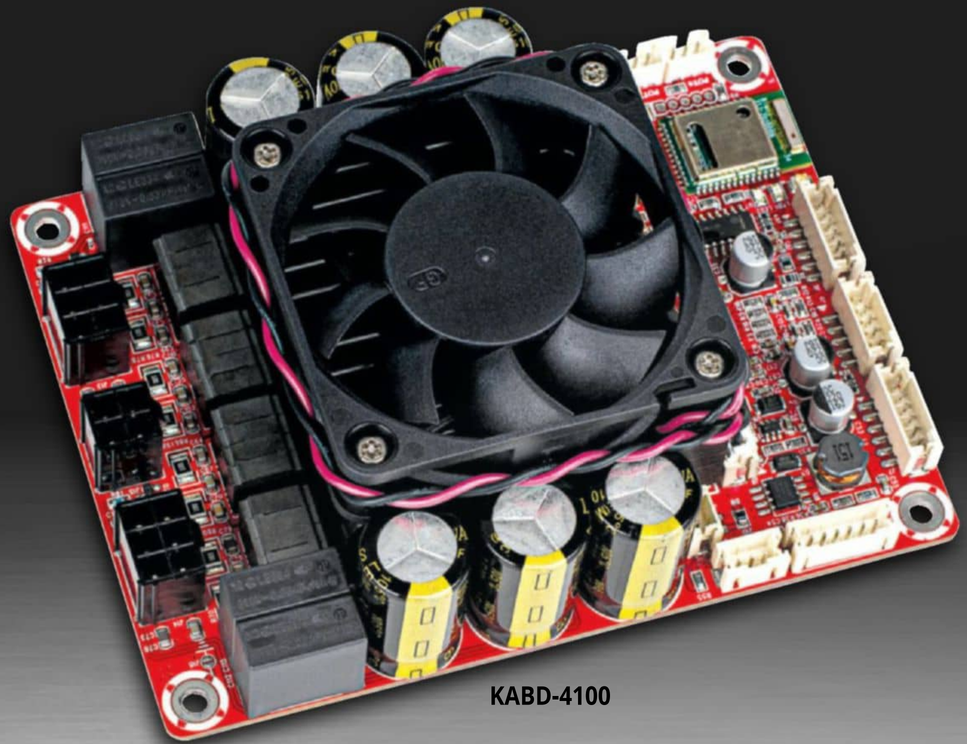

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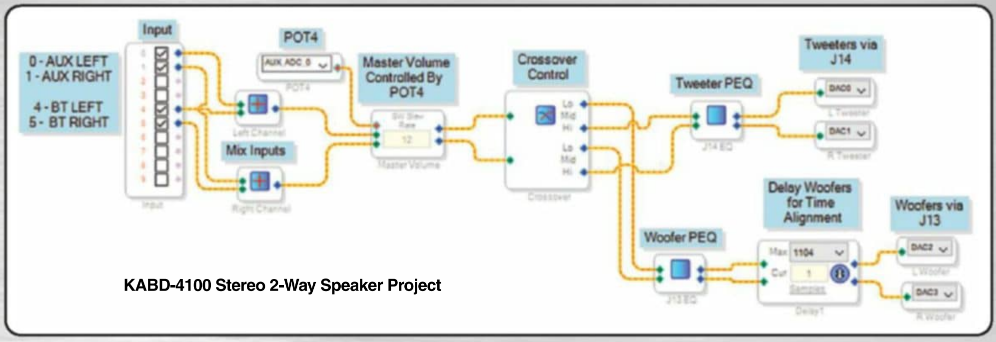

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